Control of Mine Tailing Discharges To Big River

a report prepared by

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CONTROL OF MINE TAILING DISCHARGES INTO BIG RIVER

Studies were undertaken to provide recommendations for the control of mine tailing discharges into the Big River This report provides a summary of the findings and recommendations

History

The mine tailings which are of interest in this study came from a mill located on the outskirts of Deslodge southeast of the landfill site in St Francois Co (see Figure 1) Mine tailings were stockpiled in the area near Deslodge over a 30 year period from about 1929 to 1958 These tailings were transported from a nearby smelter by slurry pipeline to the site shown in Figure 2 The material was placed in a manner so as to minimize problems as long as the pile was minimally maintained Special features of this pile will be considered in a later section of this report

In 1972, this 500 acre site was donated by St Joe Minerals Corp to the St Francois Co Environmental Corporation, a not for profit body, for use as a sanitary land fill This conversion also resulted in a shift of maintenance from St Joe Minerals to the landfill corporation Landfill operations were begun in 1973

Approximately 2 years ago (1977) a section of the tailings pile washed into the Big River Although the exact quantity of material which washed into the river is not known, estimates suggest this quantity could have been as large as 50,000 cubic yards Physical evidence suggests that much of the erosion which has taken place at this location occurred in a single event

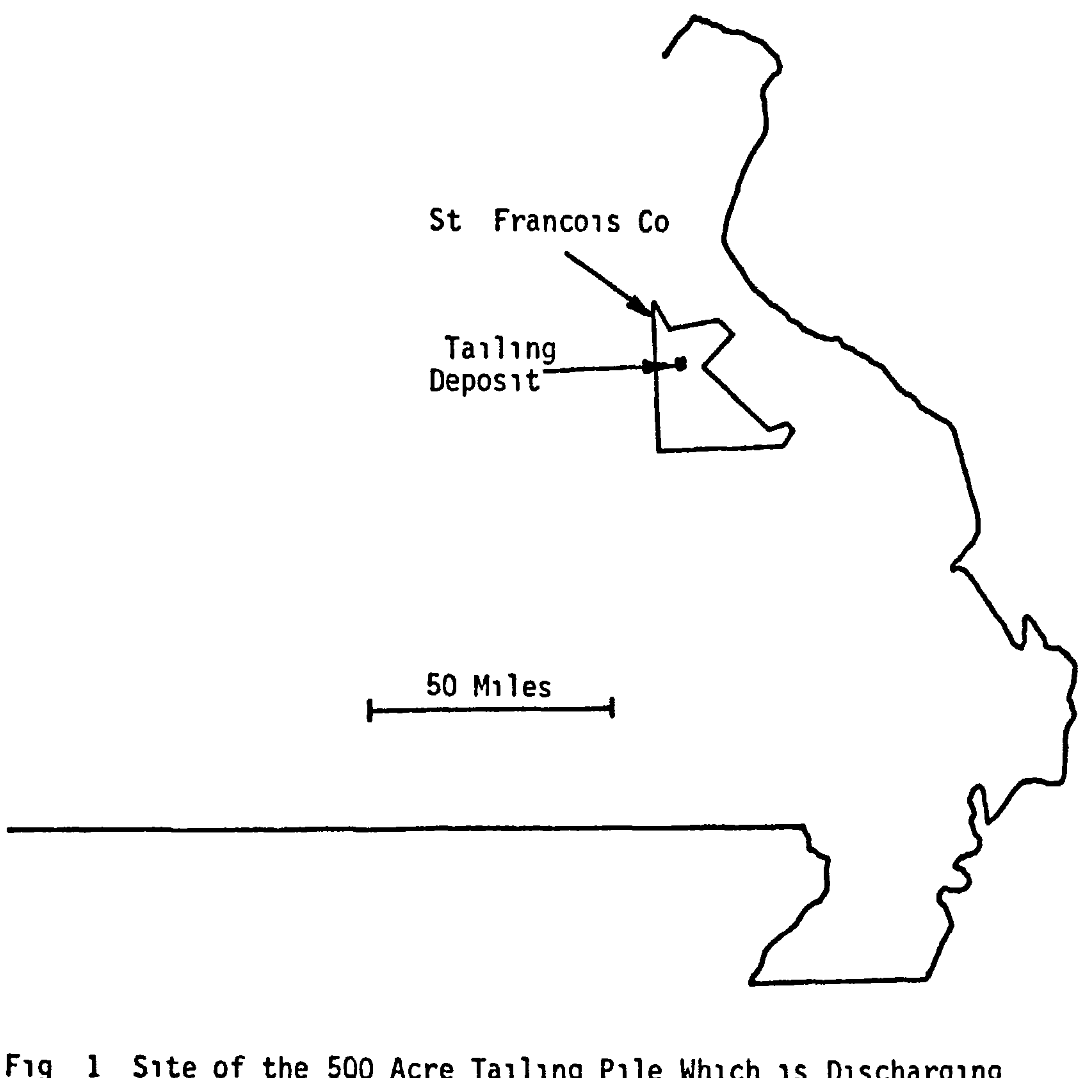

Fig 1 Site of the 500 Acre Tailing Pile Which is Discharging Tailing Into Big River

Erosion continues at this site and although the current level of discharge is small, the potential exists for significant quantities of additional material to move into the Big River Although it is not possible to assess blame for this catastrophe, it seems clear that proper maintenance could have prevented much of this discharge and better maintenance today could reduce the existing discharges to insignificant levels

The tailing pile contains numerous other sites where tailings are entering Big River Most of these discharges are minor but the potential exists for further large tailing discharges By filling the large gulleys, reshaping the pile in this location, and altering the drainage structure, most of the future problems of tailing discharges can be eliminated

Two other factors need also the be considered First, this and other local lead tailings piles will remain potential health hazards due to the blowing of lead laden dust and potential for further erosion until such time as plant growth is established Although grasses can be established, there are problems with seed germination, moisture retention and fertilization Further study in this area is suggested

Also, the current use of the lead pile as a sanitary land fill is potentially a most hazardous practice because of the possibility of mobilization of lead and zinc Preliminary leaching studies suggest that organic chelating agents can solubize a large fraction of these metals, leading to toxicity problems It is suggested that an immediate monitoring program be initiated and that this should be coupled with further research in the area of metal mobilization from mine tailings

Fig 2 Aerial Photo of the 500 Acre Tailing Deposit

Fig. 3 Aerial Photo of the Two Major Erosion Sites, The Width of the Largest Gulley is Approximately 200 Feet and the Depth About 80 Feet

Recommendations

A study was undertaken in June 1979 by the University of Missouri-Columbia Dept of Civil Engineering to propose solutions to the mine tailing discharge problems In accordance with the contract for this study, several possible solutions to the problem are proposed The following recommendations are made in order of preference of the UMC investigative team

Recommendation No I

a) Repair the major erosion sites shown in Figures 3 and 4 by refilling the gulleys with a suitable fill material At the same time, the area should be reshaped to reduce future erosion problems

b) Make alterations to the outlet drainage structure located near the erosion site to lessen the chance for overflows

c) Undertake a study of the requirements for establishement of plant growth on the tailing piles

d) Immediately begin investigation into the potential for mobilization of lead by the landfill operation

Alternative I

a) Repair the erosion sites as in Recommendation I

b) Make alterations to the outlet structure as in Recommendation I

c) Undertake an extensive seeding and fertilization program to provide stabilization of the entire 500 acre site

d) Investigate the pollution potential of the landfill operation

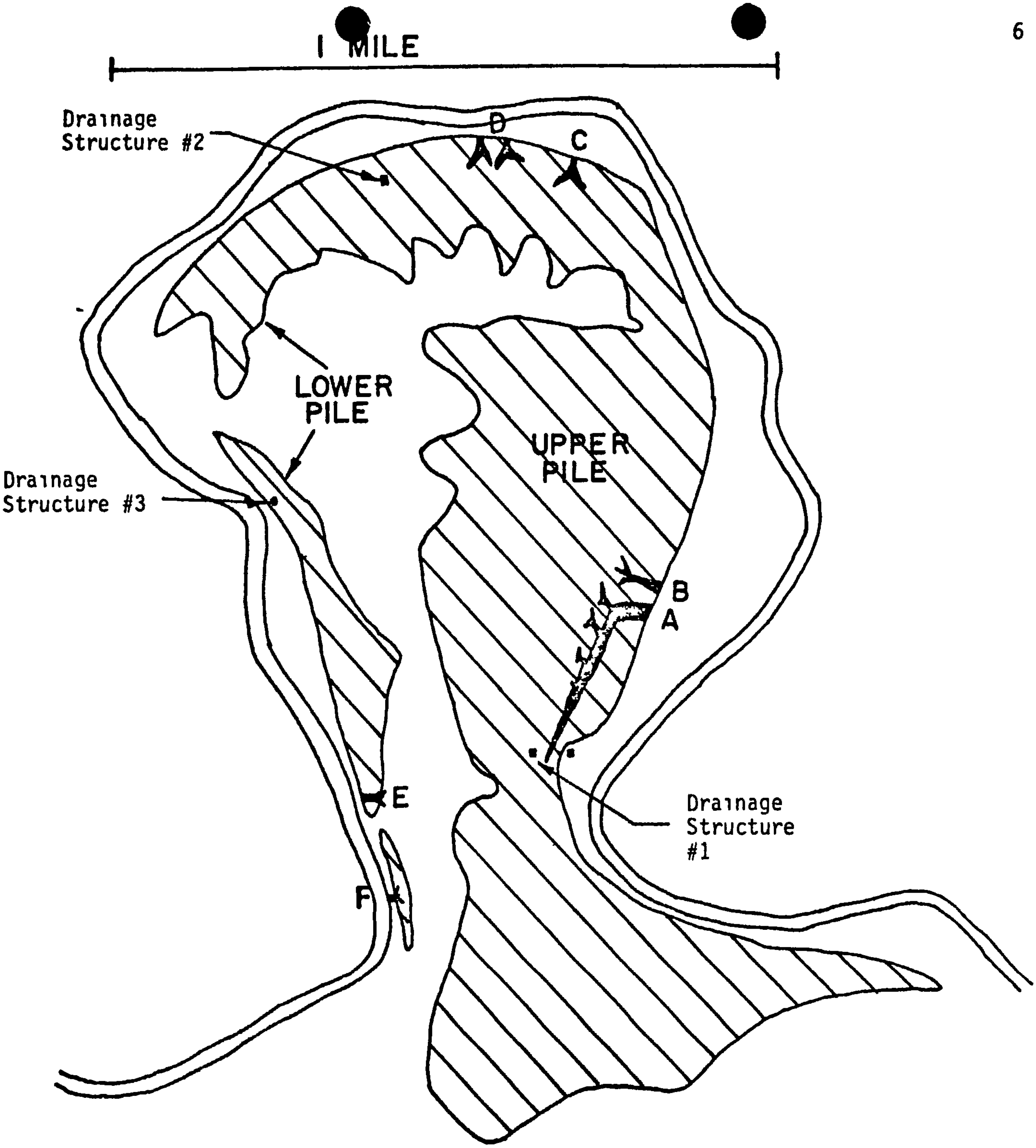

Fig 4 Plan View of Tailing Pile Showing Important Features

Alternative II

In addition to the items listed in alternative number I, repair other erosion sites as shown in Figure 4

Alternative III

- a) Improve the existing berm near the major and minor erosion sites to reduce erosion, cease disposal of tires and other residue in the eroded ditch, and improve maintenance of the drainage structure

b) Investigate the pollution potential of the landfill operation

Introduction and Background

A sketch of the site is shown in Figures 4 and 5 The location of the major source of tailing discharges is shown on Figure 5 At this site, approximately 90,000 cubic yards of material has been displaced Some of the displaced material has entered the stream and some remains adjacent to the pile in the woods between the pile and the river (see Figure 6)

Numerous other erosion sites exist These result in little or no discharge of tailing materials into the river Some of these sites are, however, potential sources of problems, the most serious being sites C and D shown in Figure 4

Plant life is almost non-existent on the tailing pile and in the areas where the tailing pile meets the original ground surface little encroachment of plant life has occurred There are several reasons for the lack of growth First is that a serious nutrient deficiency exists Second, wind erosion prevents establishment of seedings Third, moisture cannot be retained, especially on the slopes, due to the porous nature of this material Finally, the lead may cause plant sterilization, preventing reseeding by existing plants Establishment of growth will require seeding, fertilization and addition of materials such as wood chips to assist in water retention Only after growth has been established can these sites be considered reclaimed It does not appear that natural establishment of growth will occur at a reasonable pace

Three drainage structures exist One is located in a way that precludes its use This structure is located on the lower portion of the tailing pile and is filled with sand (see Figures 4 and 7) The location of the structure

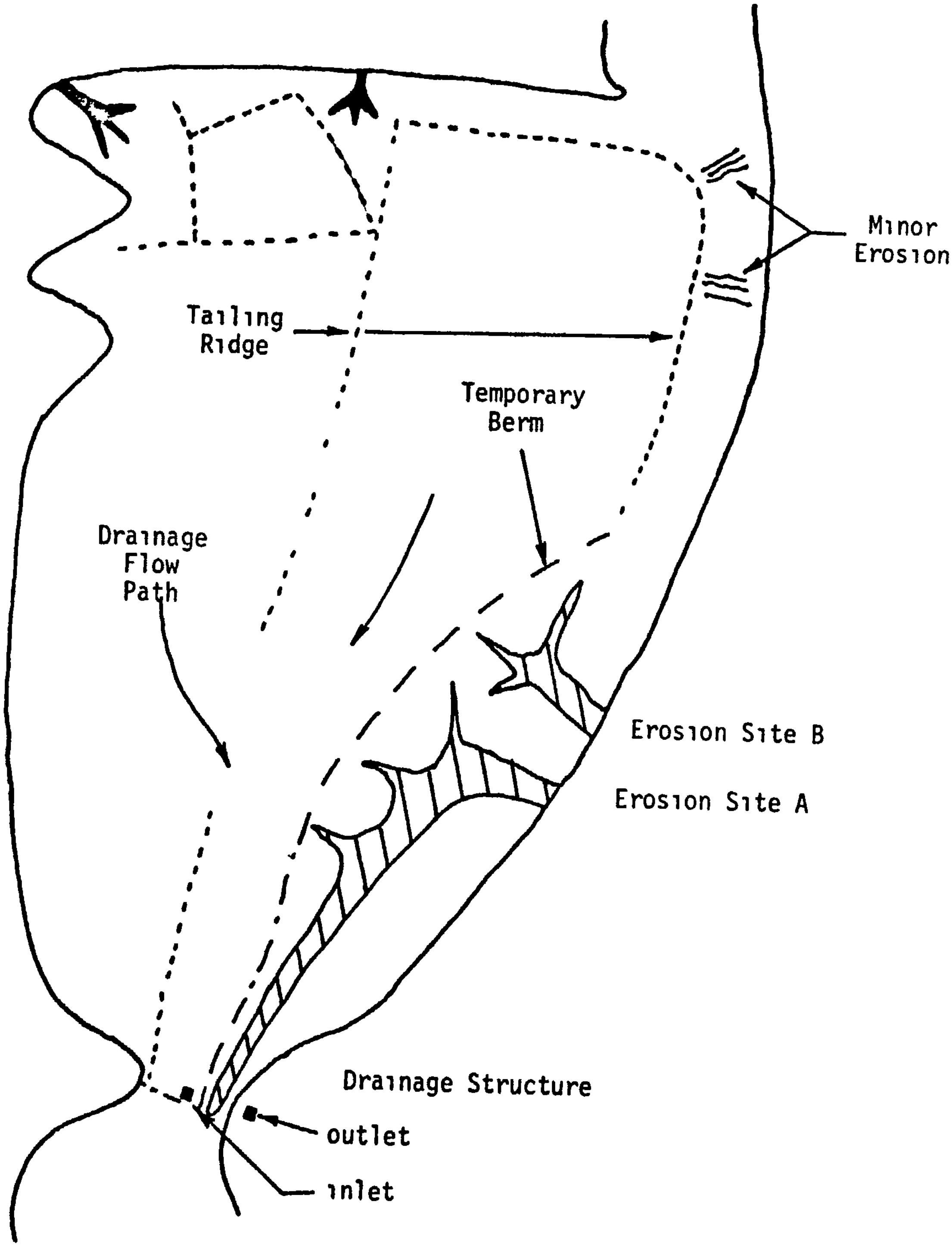

Fig 5 Plan View of the Upper Portion of the Tailing Pile

Fig 6 Deposition of Tailings in the Woods

Fig 7 Drainage Structure No 3 This Structure is Located Outside the Ridge Line and Therefore Does Not Provide Any Drainage

shown in Figure 7 is at a point where the tailing pile runs to the edge of the Big River Any overflow at this point will produce severe erosion and lead to large quantities of tailings entering the river

Another structure located on the lower level of the pile appears functional and serves as an emergency discharge system for a portion of the lower area This outlet, shown in Figures 4 and 8, carries water infrequently Most of the water reaching this area pools (Figure 9) and only under very large rainfalls will this outlet be used There is no evidence of erosion at this site, indicating that the structure works well

The outlet structure of most interest is that shown in Figures 4, 10, and 11 This structure is connected to another drain tower as shown in Figures 11 and 12 Apparently, this structure became blocked during a period of heavy rainfall and led to the massive erosion which occurred at Sites A and B This structure is now functioning properly but is subject to plugging Plugging may occur at the entrance to the structure but probably occurs in the secondary structure where the small pipe connects the two cells During field investigations over the summer of 1979, the connecting pipe, shown in Figure 13, was found to be partially blocked with debris

The purpose of the wall and connecting pipe was probably to reduce the discharge velocity so that erosion on the outer slope would not occur It is probable that the structure worked as intended for some time but in recent years, pieces of wood resulting from deterioration of the hydraulic fill structures (Figure 14) have been washed into the structure causing plugging

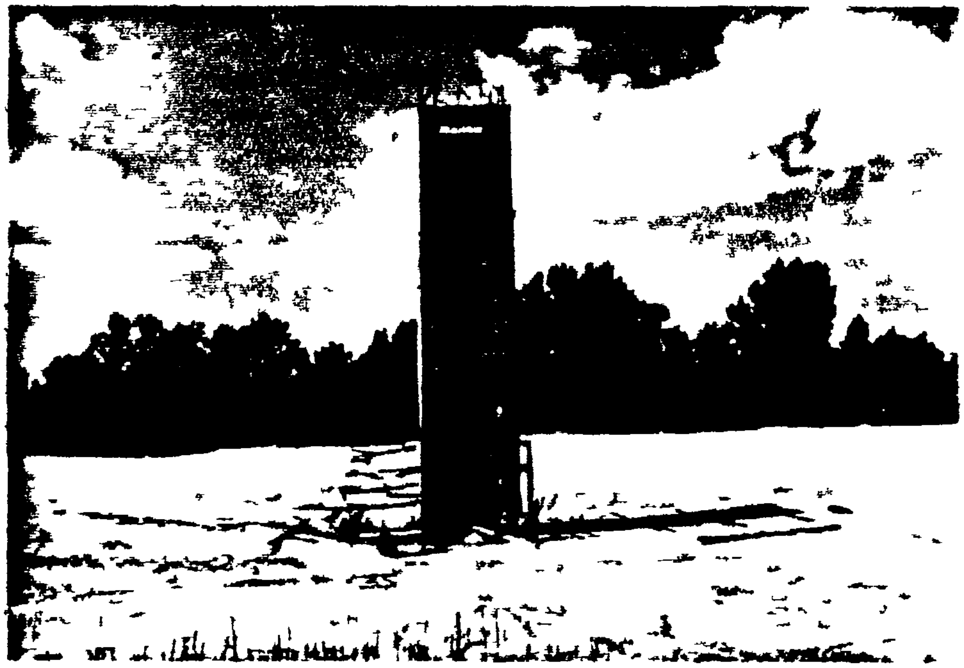

Fig 8 Drainage Structure No 2 This Structure Operates as an Overflow Outlet and Performs Effectively

Fig. 9 Ponding of Water on the Lower Level of the Tailing Pile

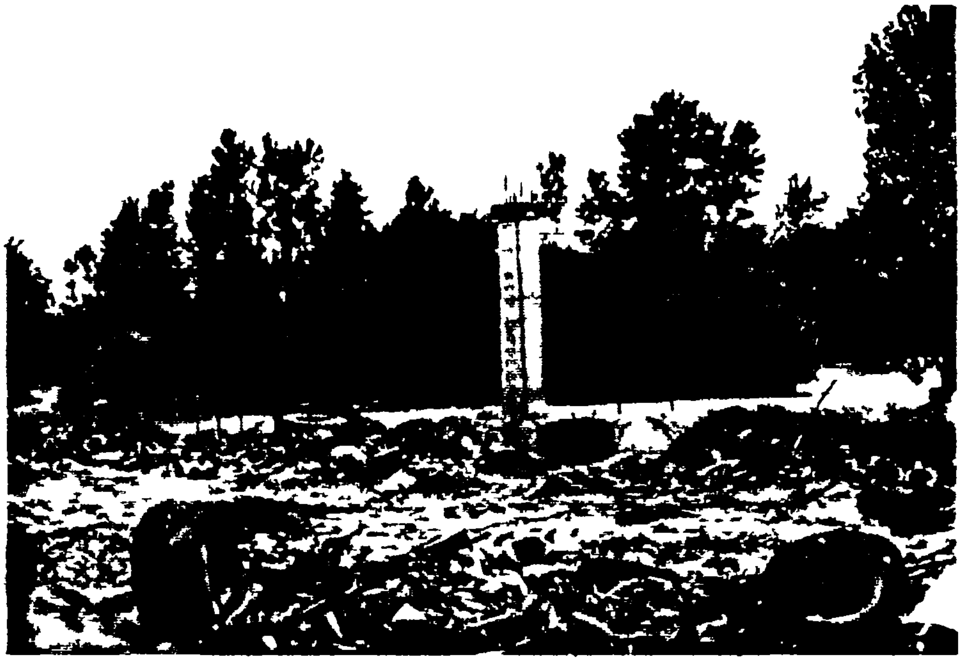

Fig 10 Drainage Structure No 1 This is the Drainage Structure That Became Plugged and Resulted in the Overflow and Erosion

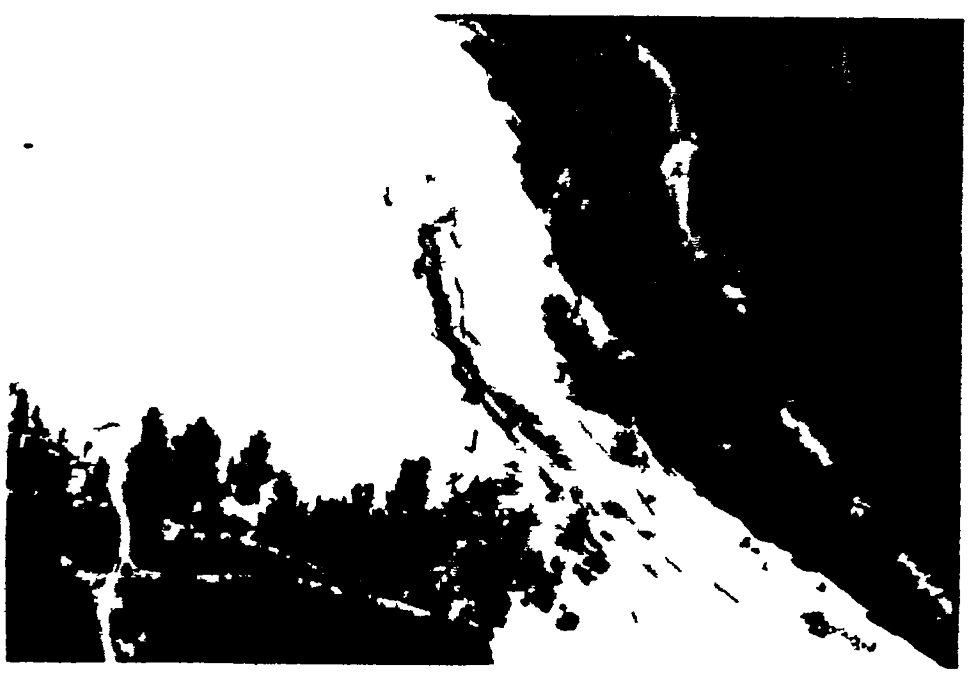

Fig 11. Aerial Photo of the Drainage Stucture No. 1.

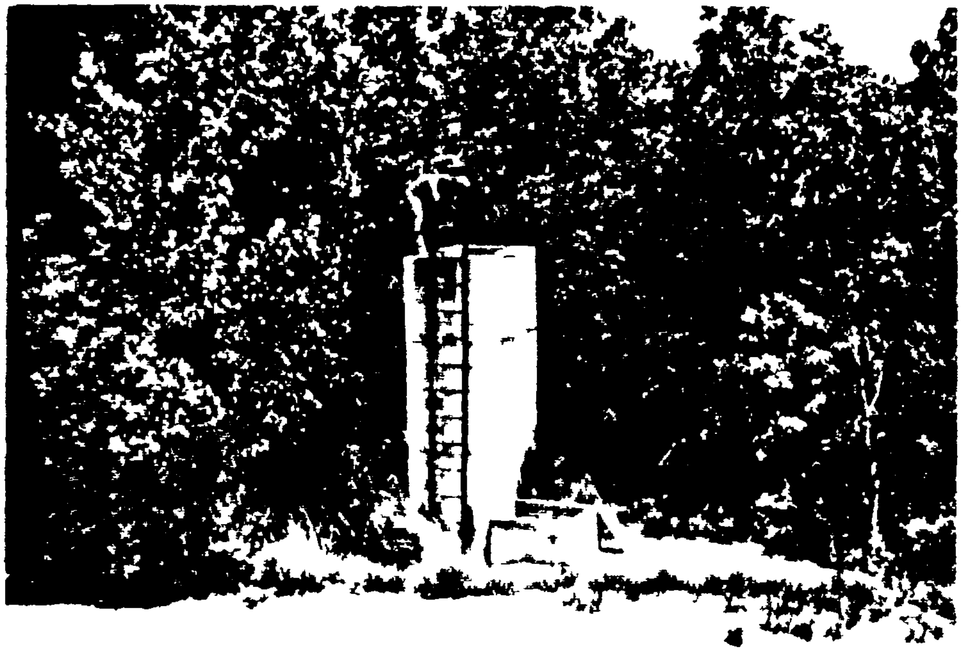

Fig 12 Outlet Portion of Drainage Structure No. 1

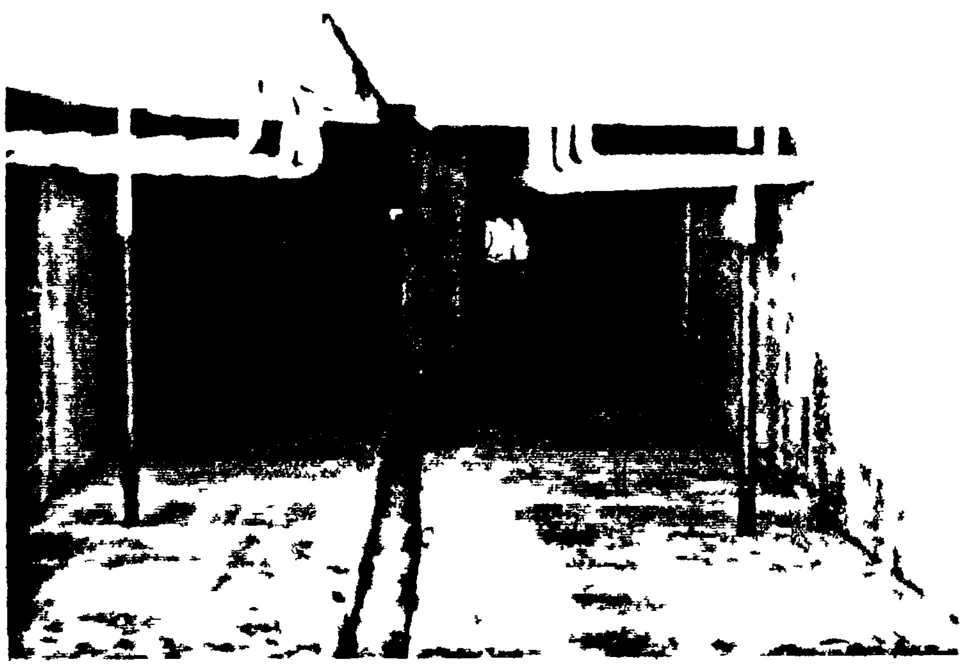

Fig 13. Top View of Outlet Drainage Structure Showing Center Wall and Small Pipe

Fig 14, View of the Top of the Pile Showing Debris Remaining From the Hydraulic Fill Structure

The existing lanfill operation is also a potential source of problems The current operation is located away from the serious erosion sites and there is no firm evidence to indicate that the land fill operation has contributed to the erosion problem However, in an effort to stop the erosion, debris, primarily tires, has been placed in the gulley Several photos of this debris are presented in Figure 15 These tires have undoubtedly assisted in preventing some water from reaching the gulley although they have not been of major importance

Some of the debris, including tires and strips of plastic, has reached the river and is unsightly Although no harmful biological effects should result from this deposition, the benefits from these deposits have already been realized and continued deposition should cease The tires which have washed into the river should be removed

A more serious potential problem exists with regard to the sanitary land fill The liquid runoff (lechate) which results from landfilling usually has a low pH and contains large quantities of organic material Under these conditions, heavy metals may be leached from the tailings and carried into Big River Tests conducted at the Environmental Trace Substances Laboratory have yielded the data shown in Table 1

The nitric acid extractable concentration should represent the total quantity of metals in the tailings, while the distilled water extraction might be close to what is extracted by the movement of rainwater through the tailings Most of the lead and zinc which is extractable by distilled water can be expected to be diluted and reprecipitated once it reaches the stream and data obtained from earlier studies indicates the level of lead and zinc in the Big River is below the detection limits

Fig 15 Tires and Other Debris Used In An Attempt to Control Erosion in the Large Gulley

Table 1 METAL ANALYSES

Tailings Samples

	Clay (μg/g dry)			Sand (μg/g dry)		
	Water	EDTA	HNO_3	Water	EDTA	HNO_3
Ag	N D	N D	N D	N D	N D	N D
Al	16	37	3800	16	21	840
B	N D	N D	16	N D	N D	14
Ba	05	8	14	N D	5	3
Be	N D	N D	1	N D	N D	4
Ca	820	6400	>30,000	780	4400	>30,000
Cd	N D	3 2	14	N D	5 8	25
Co	N D	20	41	N D	8 9	11
Cr	N D	N D	N D	N D	N D	N D
Cu	7	70	180	1	16	77
Fe	100	670	>16,000	130	600	>16,000
Li	N D	N D	3 3	N D	N D	N D
Mg	460	2000	>30,000	360	1800	>30,000
Mn	12	160	2300	14	100	3000
Mo	N D	N D	N D	N D	N D	N D
Na	15	17	60	2	16	120
Ni	N D	8 2	45	N D	3 4	16
P	N D	13	420	N D	14	130
Pb	20	2200	2400	26	720	850
Sr	4	2 3	33	2	1 4	36
Ti	N D	N D	N D	N D	N D	N D
V	N D	N D	N D	N D	N D	N D
Zn	3 4	220	680	14	230	1000
K	400	730	1700	20	28	240
pH*	8 8	6 05		6 4	6 05	

*pH of blank EDTA - 6 05

H_2O - 5 6

Tests conducted by Environmental Trace Substance Research Center

The EDTA extraction results would represent the potential for extraction by the landfill leachate This material would be chemically bound by organics and might remain in solution, creating potentially serious ecological and human hazards

The landfill operation provides some potential benefits to the tailing site Most important is that their permit requires the placement of a soil cover once land filling is completed In addition, organic matter necessary to support plant life is being added to a site which is devoid of organic material However, the potential for creating an ecological desert out of Big River due to lead contamination is enough to offset these potential benefits The land filling operators have not shown themselves to be responsible citizens with regard to maintenance of the tailing pile so it is unreasonable to expect them to maintain a careful watch on leachate flow

<u>It is therefore recommended that DNR immediately undertake a monitoring program at the landfill site to locate any sources of leachate and to characterize the quality of this material It is further recommended that studies be undertaken to determine the leaching potential and movement of metals resulting from contact between leachate and tailings Because of the serious potential for contamination of the Big River, these recommendations are applied to all four of the suggested options</u>

Details of the Site

A sketch of the site is provided in Figure 4 At present there are about 8 sources of tailing discharges Each of these is indicated on the series of sketches in Figures 5, 16, 17, and 18 The most serious is the site shown in Figure 5 where two separate erosion sites exist In Figure 19, a series of profiles are shown for site A Although there are some discontinuities and side ditches in this gulley, it can easily be represented as a triangular section The volume of material which has been displaced is estimated at 90,000 cubic yards Some of this material is located at the foot of the pile in the woods and a larger fraction has been washed downstream Minor erosion continues at this site

At site B, erosion also in continuing The site contains several erosion ditches but in addition, the entire area is at a much lower elevation than the center of the tailing pile, making this a likely location for further runoff and large scale erosion problems

It is recommended that the 90,000 cubic yards from site A be entirely replaced It is recommended that the ditches at site B be filled and that a surcharge of material of ten feet in depth be added to this area so that this location is raised to an elevation above that of the main portion of the pile The corrections at site B will require approximately 40,000 cubic yards of material

The continuing erosion at these two sites has resulted from alterations in the topography such that the area at the top of the outer slope is flattened rather than crowned Water can collect on the flat surface and run off down the edge of the tailing pile cutting channels which continue the wash of tailings into the river In all instances where the top of the tailing pile is flat rather than crowned, erosion has occurred See Figure 20 A sketch of the existing and proposed ground profile at site B is shown in Figure 21 The first 3 recommendations all call for refilling these gulleys and reshaping the area

The reshaping of the area will require that the top of the tailings pile be bowl shaped to insure that all water is channelled to the drainage structure A logical source of material is the nearby ore pile These materials are located close-by and are coarsely graded Course materials on the crown and outer slopes eliminates erosion Some finer materials can be obtained by excavation of material from the top of the pile This will provide for a stable and impervious fill and could produce a small "lake" in the center of the pile At present, about 80% of the upper level of the pile drains directly through the drainage structure The upper level of the pile drains directly through the drainage structure The runoff contributes silt and also washes in wood from the decaying tailing placement structure If the pile were reshaped to provide a holding pond, most of the water would evaporate or seep into the ground In addition, much of the silt which currently washes into the drainage structure would be settled out in the pond, along with pieces of wood which can potentially block the outlet The pond would act as an overlfow basin in much the same manner as drainage structure No 2

The only drawback to the use of excavated pile materials is that below the surface, this material is wet and sticky and may be difficult to move

As an alternative to providing fill for the entire area, the smaller gullies can be filled and a more substantial berm can be constructed This can minimize the wash of tailings into the river if properly maintained

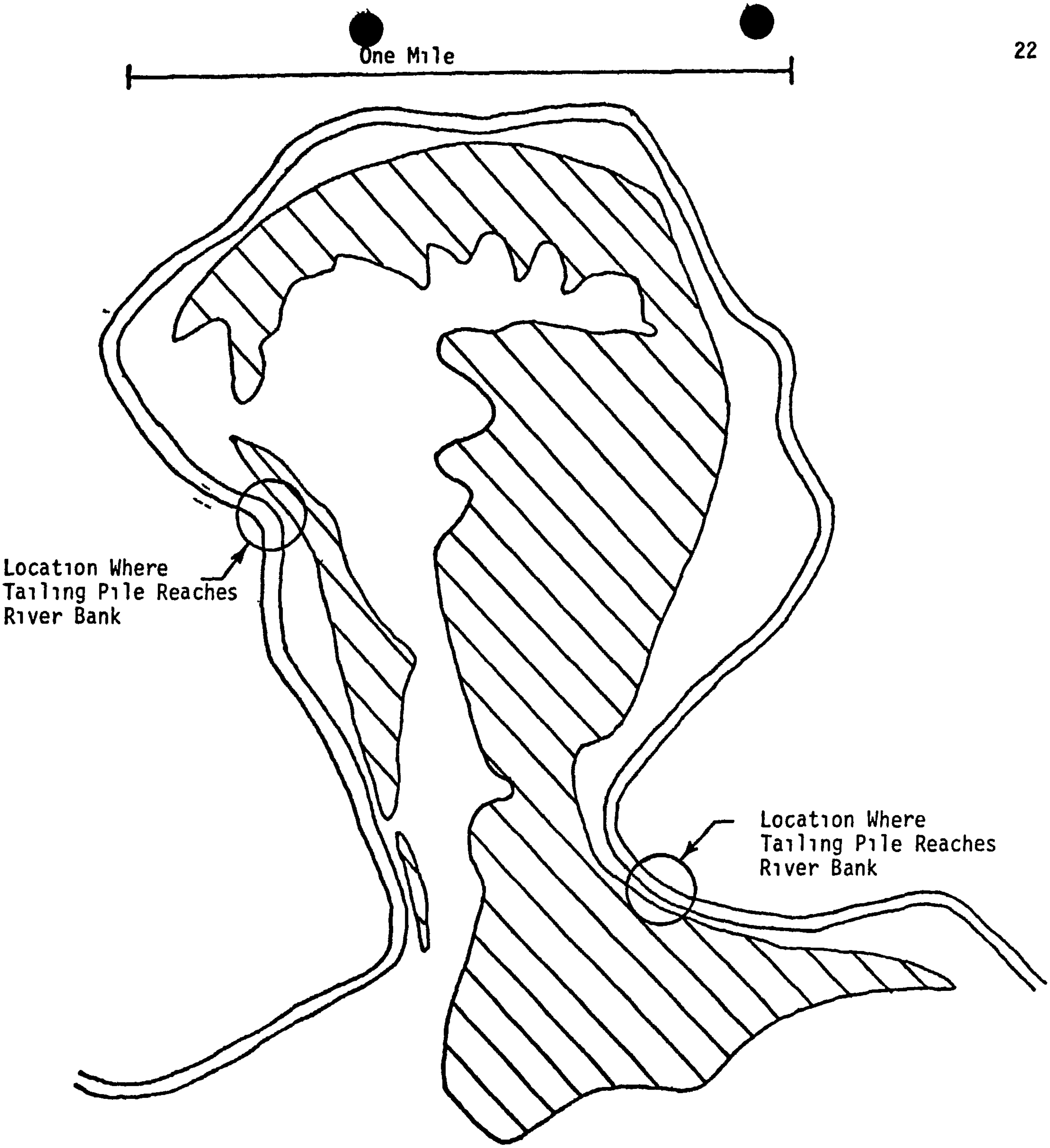

Fig 16 Location of Two Sites Where the Tailing Pile Reaches the River Bank

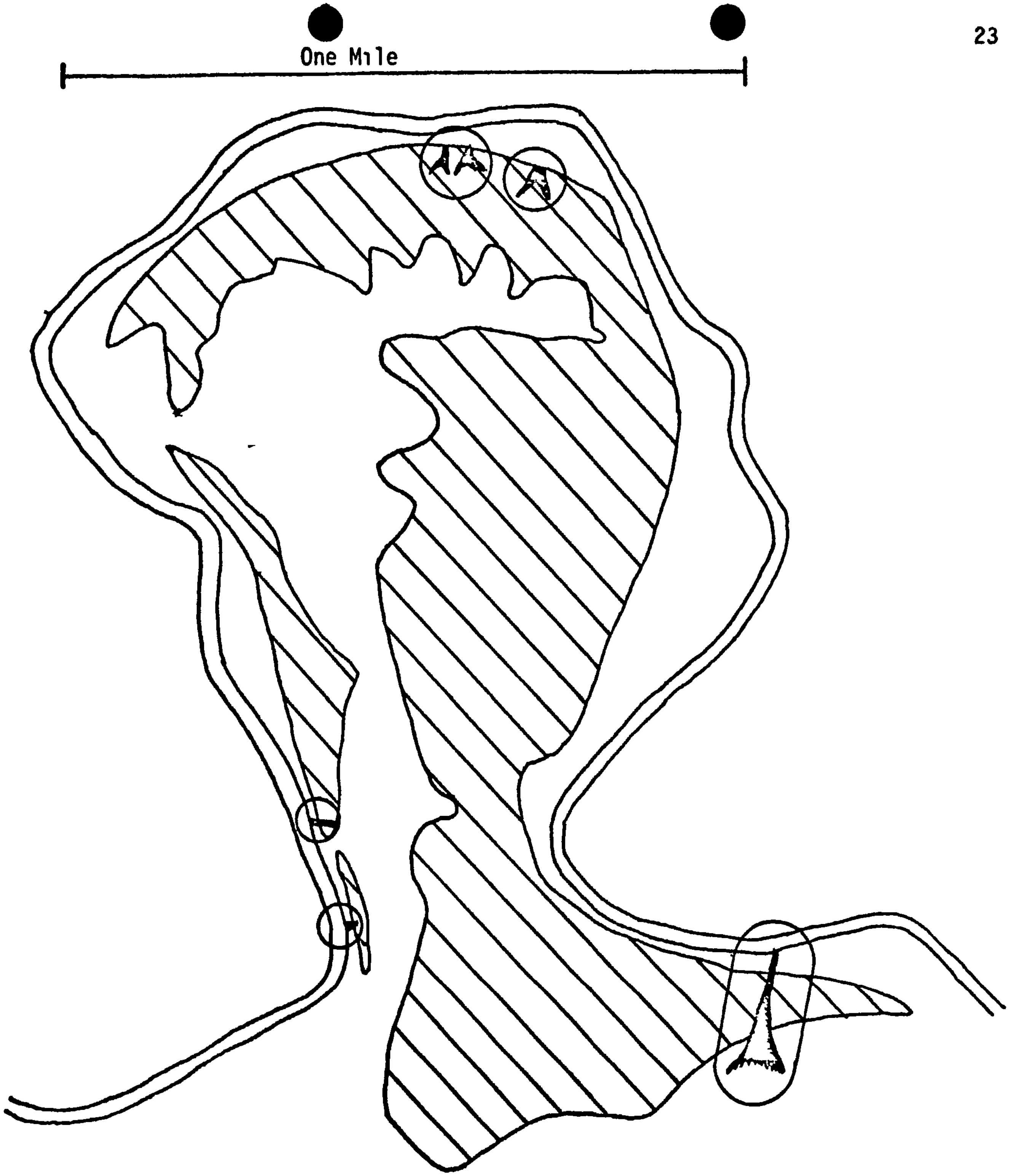

Fig 17 Minor Erosion Sites Which May Contribute Small Quantities of Tailings Into the River

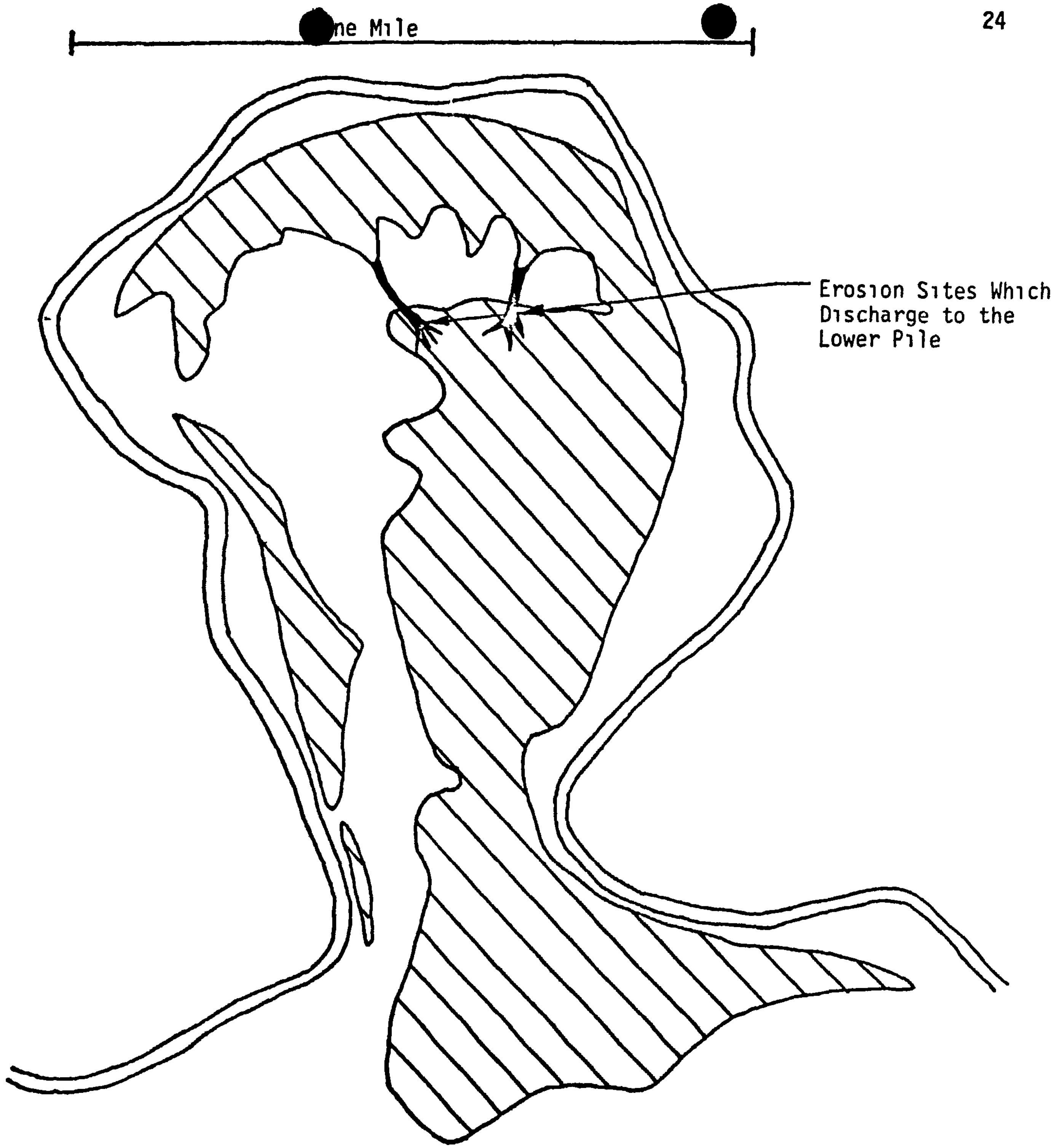

Fig 18 Erosion Sites on the Upper Pile These Sites Appear Serious But Contribute No Discharge to the River and Constitute no Potential Hazard

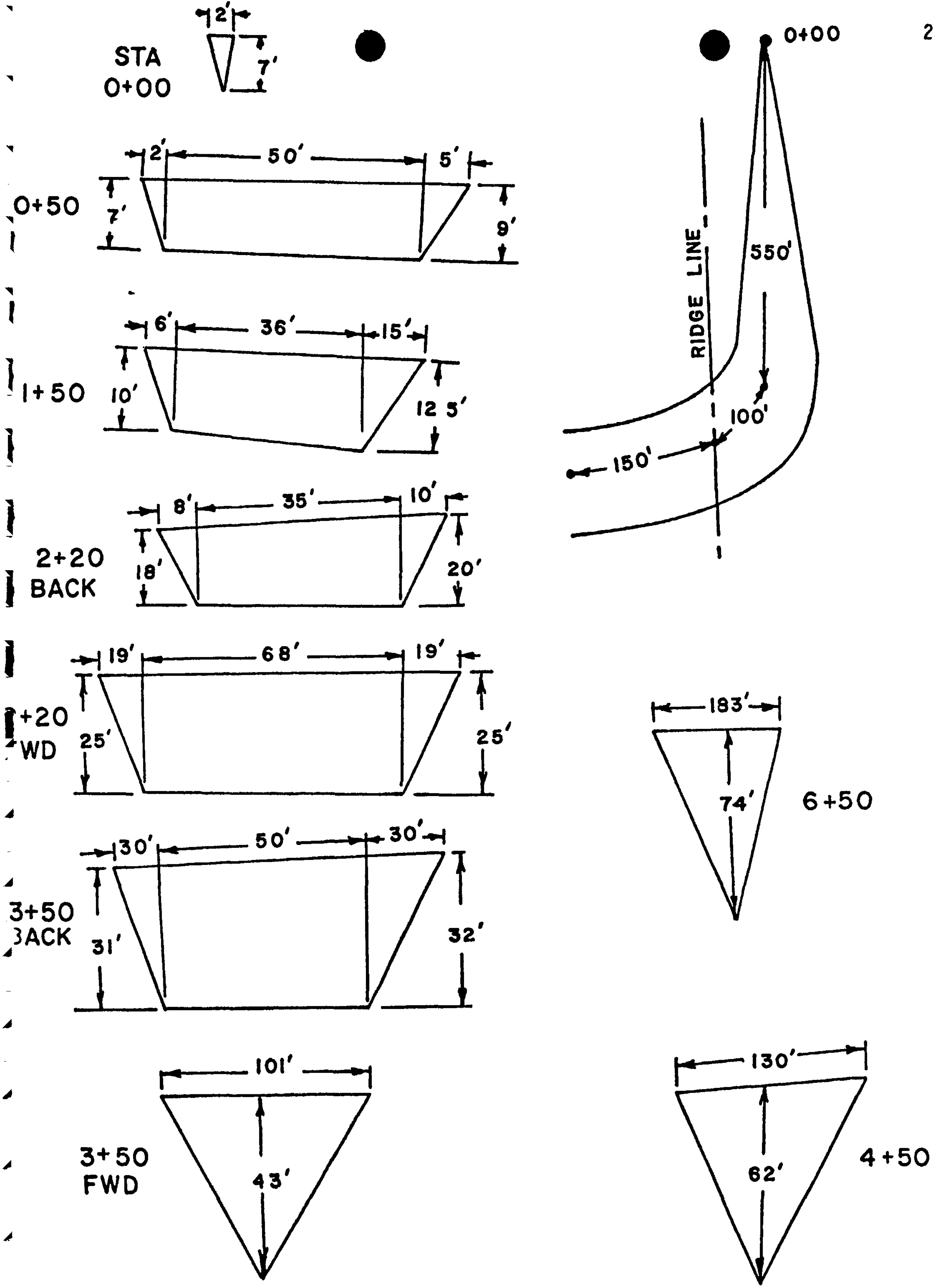

Fig 19 Plan and Cross-Sections of the Major Gulley

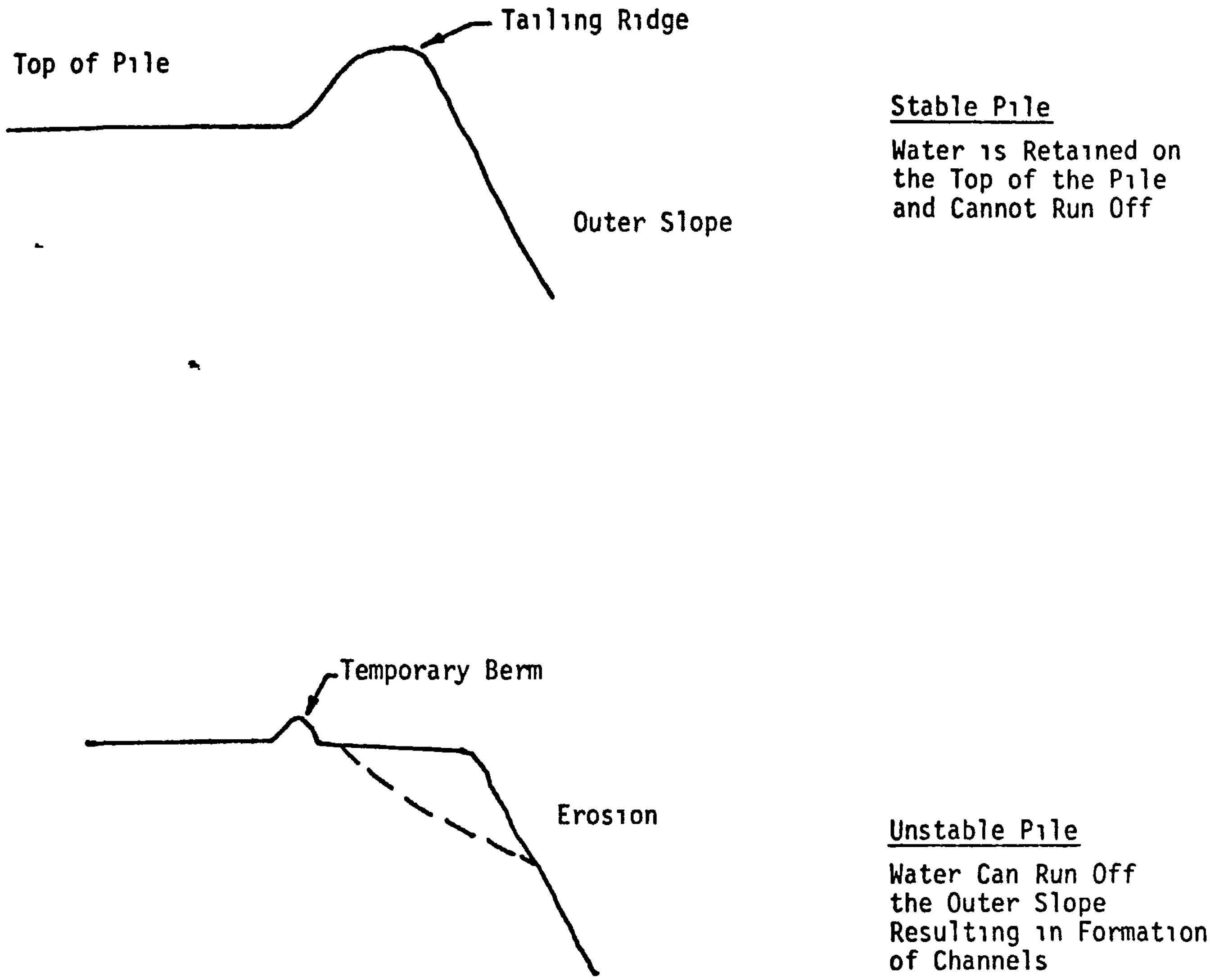

Fig 20 Sketch Showing the Manner By Which Erosion Occurs

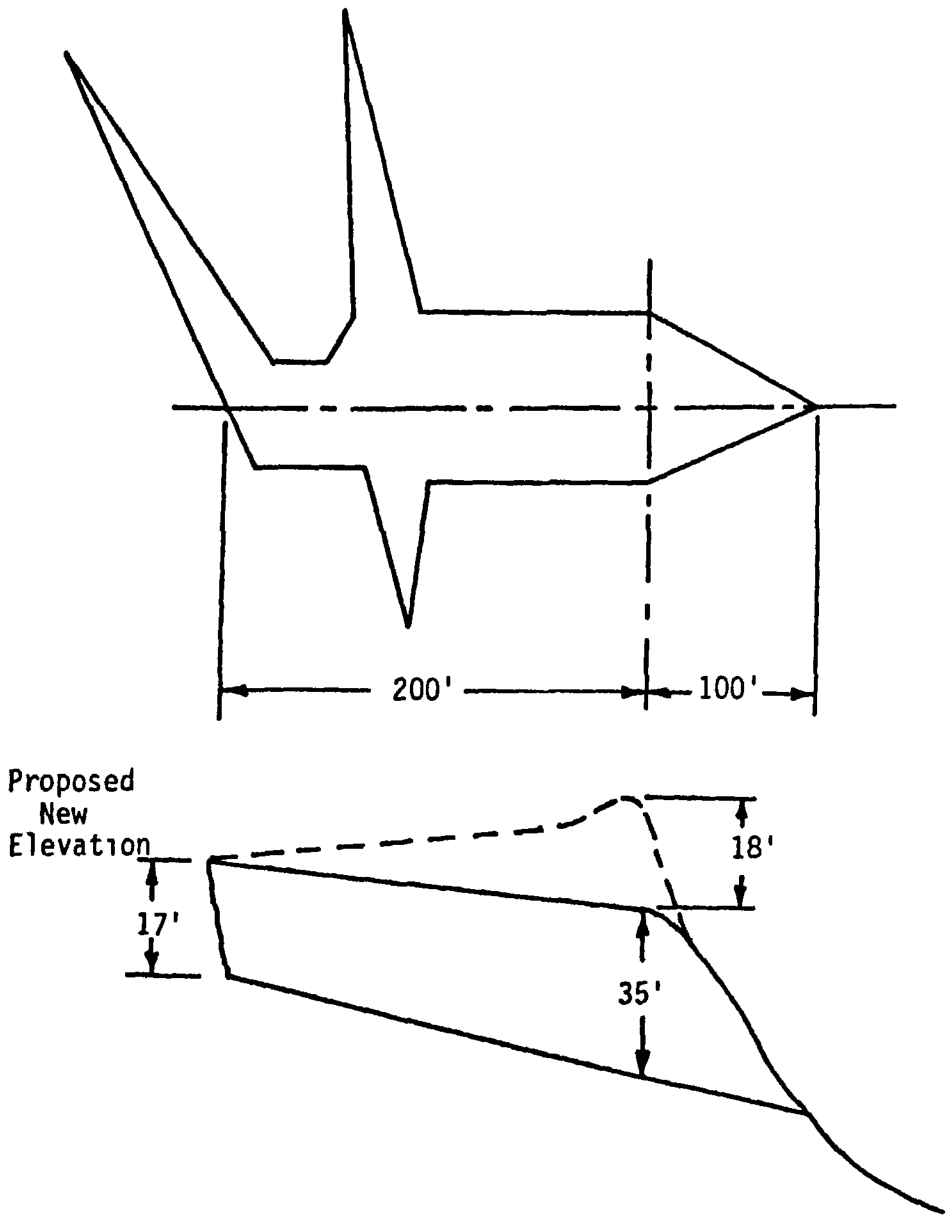

Fig 21 Plan and Profile of Erosion Site B and Proposed Fill Elevation

Deposition of approximately 40,000 cubic yards of tailings into the large gully and mechanically reducing the steep slopes should eliminate most of the erosion problem although the large ditch will remain and will be a potential source of problems if the drainage structure fails to perform

About 10,000 cubic yards of material and a new berm at site B could also reduce tailing discharges at this location and this minimal solution is an alternative to placement of a material surcharge at this location

The UMC team believes that either of the previously discussed fill options for sites A and B will eliminate the tailing discharges in the near future However, complete filling of the gulleys is favored for the following reasons

a) The partial fill and berming will require constant maintenance and repair from damage due to minor erosion and motorcycle riding

b) Tailing discharges will probably continue, although at a very minor level

c) The entire area will remain structurally sensitive due to the original erosion of the slopes and because finer material, subject to erosion will remain exposed to rainfall

d) If the drainage structure becomes plugged, massive erosion will reoccur If the entire area is rebuilt, the water which could back-up due to plugging of the drainage structure should pool and eventually disappear due to evaporation and permeation into the tailing

The minimal fill and repair solution should be undertaken as a <u>temporary measure</u> only if funds for repair are unavailable St. Joe Mineral Corp has indicated a willingness to provide most of the material required for minimally restoring the area If the berming and minor filling option is used, it should be recognized that future tailing discharges and repairs are likely

Other Erosion Sites

Several other erosion areas exist Some of these sites contribute tailings to the river although the amounts are minor Two sites exist, as shown in Figure 16, 22, and 23, where the tailing pile runs to the edge of the river and under high flow conditions can be directly eroded Several other sites contribute tailings to the river One of these, shown in Figure 17 and marked as Site G is located away from the major tailing deposits in an area owned by the St Joseph Lead Co Another is in a very small tailing deposit behind the area where fescue has been planted and is shown in Figures 17 and 24 Several other sites are shown in Figures 17, 25 and 26

All of these sites are considered minor No repairs of these sites are recommended Several of these sites were considered to be uncorrectable problems Discharge from the site owned by St Joe Mineral Corp (Site G) probably can be minimized by constructing small holding basins to settle out tailings The discharge marked as Site F on Figure 17 could be eliminated by rebuilding the rock wall on this site The area marked Site E cannot be repaired At Site E tailings were placed in a area through which an intermittant stream runs The tailings from this site have been washed away and only minor erosion is now occuring The sites marked as Sites C and D can be repaired by adding fill and reshaping the ground These are the most likely spots for additional erosion control

Fig 22 Location Where Tailing Pile Reaches the River

Fig. 23, Site Near Drainage Structure No 3 Where Tailing Pile Reaches the River

Fig 24 Erosion Site F

Fig. 25, Erosion Site D

Fig 26 Erosion Site E

Fig. 27. Area Where Fescue Has Been Planted

Studies of Plant Growth

A series of studies were undertaken to determine the requirements for maintaining grass stands on the tailing pile This work is summarized in Appendix A Although the results were not conclusive due to the short growing period, several trends can be seen from the data presented in Table 2 First, wood shavings were helpful in getting fescue established Second, sewage sludge was not beneficial Finally, the use of sewage (lagoon) effluent appeared to be beneficial but no more than the addition of wood shavings

Results from soil moisture tension tests (Appendix B) varify the data obtained from the grass study These data show that wood chips greatly increase the moisture holding capacity of the tailings and provide for improved growth conditions if seeds are drilled rather than broadcast

A stand of fescue has been established at one location (Figures 27 and 28) Considerable erosion has occured around the root structure of these plants The fescue plot is located in a flat area behind a small ridge where water often pools This fescue plot provides ample evidence that grasses can be established where wind erosion is not severe and where slopes are not steep

Conversations with John Kennedy of St Joe Mineral Corp provided the following information

> They had good success on slopes less than 10% with a seed mixture of Fescue, Brome, Orchard, Timothy, Alfalfa and Sweetclover Seeding was done at a rate of 30-40 lbs/acre with fertilizer added at the following rates N-45 lbs/A, P and K - 30 lbs/A The best germination resulted from a February seeding
>
> The particular grass that dominates after germination appears to depend upon the altitude of the slope Starting at the top of the slope the following succession is observed Brome, Orchard, Fescue with alfalfa and clover dispersed among all three grasses

Table 2 Number of Seeds Germinating After Six Weeks

	Control		Wood Shavings		Lagoon Effluent		Sludge	
Fescue	8*	13	14	62	11	66	Severe Grass-hopper damage	
Switch	20	35	18	48	13	42	17	7
Sandlove	0	12	7	18	7	2	11	0

* Left column = Surface Broadcast

Right column = Drilled Seed

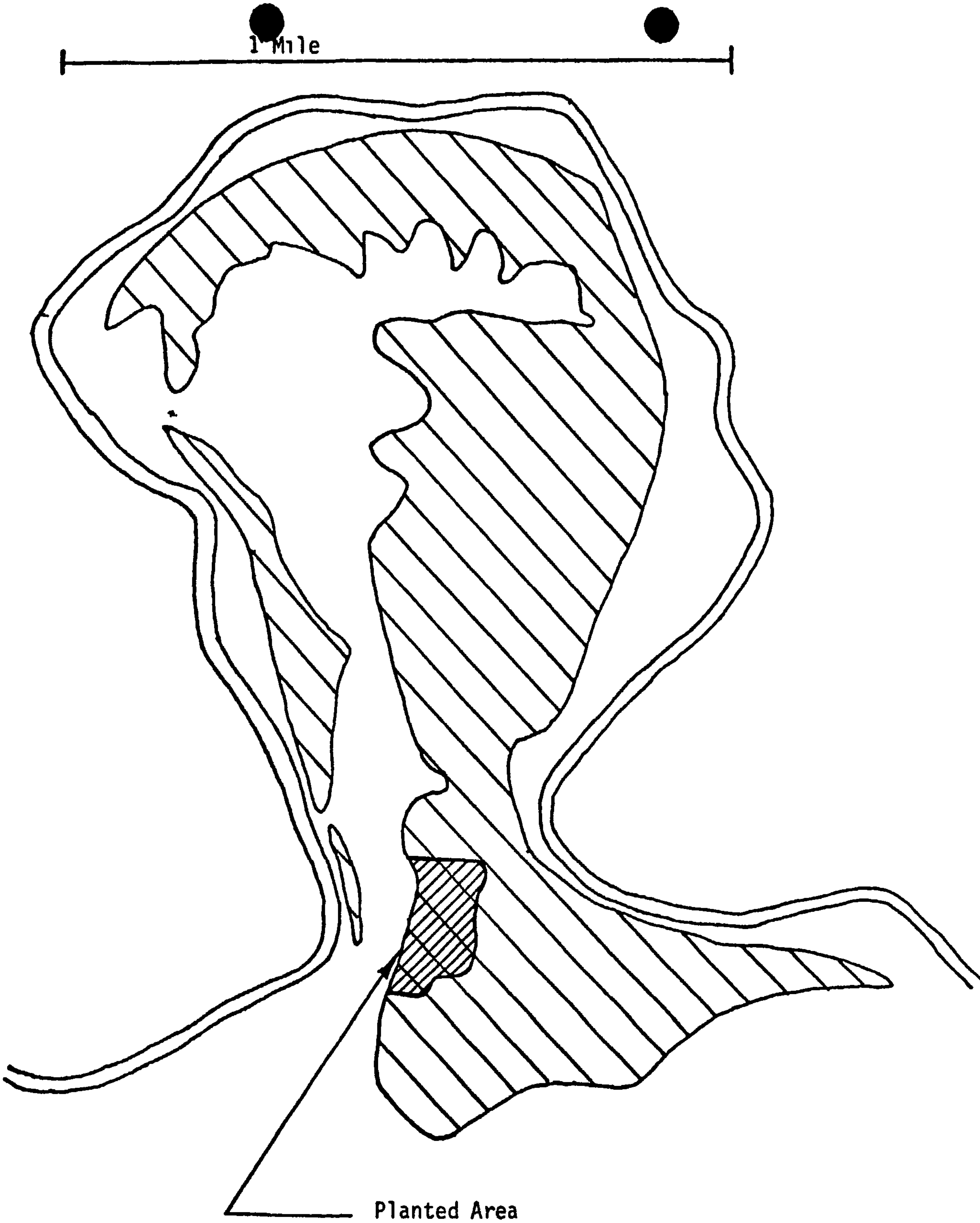

Fig 28 Location of Fescue Stand

Distinct lines of demarcation occur between grasses The succession could be due to moisture availability or mineral content of the soil material

Mulching had been attempted with straw, straw plus asphalt, and Cohecex (commercial product) The straw and straw-asphalt blew away Limited success was achieved with Cohecex

They had success with three species of tree - Poplar, Black Locust and Autumn Olive

The problem of establishing grasses appears to be one of wind erosion and water availability The constant blowing either carries the seed away or covers the seedlings with sand One solution might be to control the wind erosion by establishing wind breaks (mechanical or planting large trees) and seeding the protected areas into an organically mulched soil bed The organic mulch could be sawdust or wood chips

Further conversations with the County agent indicate that grasses from the tailing piles may be producing sterile seeds This may explain why planted areas can provide good stands of grass but grasses don't spread to other areas The sterility problem may be due to the lead in the tailings

It appears from the tests and conversations with several agriculturalists associated with the tailing areas that plants can be established on the piles but a single planting may not insure that these areas will be recovered For this reason, two alternative recommendations are made relative to seeding of the tailing pile The primary recommendation is that a study be undertaken to further assess the plant supporting characteristics of the tailing pile and that this study serve as the basis for future seeding and fertilization An alternative is to seed and fertilize immediately in conjunction with treatment with wood chips

Although studing the problem will delay the planting operation for several years, the UMC investigators believe that such studies are necessary if these areas are to be successfully recovered For example, personnel from both DNR and EPA have suggested that sewage sludge could be very useful in enhancing plant growth However, data in Table 2 show that sewage sludge actually appears to be detrimental This may be because the organics in sludge solubilize the lead and zinc and increase the toxicity Metal mobilization in the presence of organics is also shown by the data in Table 1 A case can be made for immediate seeding, however The growing of grass will greatly reduce the blowing of lead laden dust around populated areas and this may have a direct health benefit Even if the recovery is not as rapid or complete as desired, substantial benefits will be derived

<u>In summary, DNR is given a option of immediate seeding or supporting a research effort which will lead to a seeding program</u>

Soil Tests

Soil tests were conducted to determine the suitability of tailing material for refilling of erosion gulleys, to determine the suitability of this material for supporting earth moving equipment, to determine if soil stabilizing additives are needed and to determine the nature of the materials at different locations in the pile The results of these studies are contained in Appendix A

A summary of these data is presented as follows

The area consists of two distinct soil gradations On the outer slopes, the material can be catagorized as sand This material is uniform down to a depth of at least six feet In the center or top of the pile the material consists of alternating layers of sand and clay The clay material below the surface is moist and is near the liquid limit At moisture contents exceeding the liquid limit, the soil is unable to support earth moving equipment

The course sand on the outer slopes prevents erosion by reducing the channeling of water On some of the lower piles, the outer slopes contain a much finer material and contain erosion channels of several ft in depth (See Figure 29) It is believed by the UMC investigators that when the gulleys are refilled, course material should be used to cover the outer slopes and tops of the pile to minimize future erosion The existing ore pile located about ½ mile from the major erosion site contains course sand, similar to that which existed prior to the erosion This material should serve as an excellent replacement material

Other parts of the pile contain layers of sand and clay These vary in depth but none of the individual layers appear to exceed two feet in depth The layering is probably due to the hydraulic fill placement of these materials

Fig 29. Minor Erosion Site on Outer Slope

This material is very impervious and also appears to be physically stable This material will support earth moving equipment without difficulty but because of the retained moisture may be difficult to excavate and could cause equipment to get stuck In Figures 30 and 31, the clay layers and outer sand characteristics are shown

As placed, the outer slopes of most of the tailing pile are stable However, any disturbance of this material results in movement Therefore, recreational use of this site can result in slope failures and enhance further erosion It is important for future maintainance that motorcycles and dune buggies be kept off this area until the area can be stabilized by plant growth If recreational activity is permitted, movement of the surfaces will destroy existing plant growth

Soil stabilizing agents were not found to be feasible Because this material is primarily calcium based, liming is not useful Stabilization can be accomplished using cement, but this is not environmentaly acceptable

Drainage Structures

The installation of additional drainage structures is not proposed Of the three existing drainage structures, only structure No 1 (Figure 10) requires modification Drainage structure No 1 is a double tower arrangement Blockage appears to occur at the second tower at the center wall and small pipe These should be removed as shown in Figure 32 In addition, some of the silt which has been deposited at the water inlet should be removed and the area altered to permit easier water access to the structure It appears that when the 6 inch pipe becomes blocked in the second tower, silt deposits in the bottom of the water inlet structure and connecting pipe (Figure 32) Silt deposition in the connecting pipe can be reduced by removing the barrier wall and pipe and reducing the amount of debris that enters the structure

F1g 30 Photo of Alternat1ng Sand and Clay Layers

F1g 31, Photo Show1ng Course Outer Slope Material and F1ner Mater1al Exposed by Eros1on

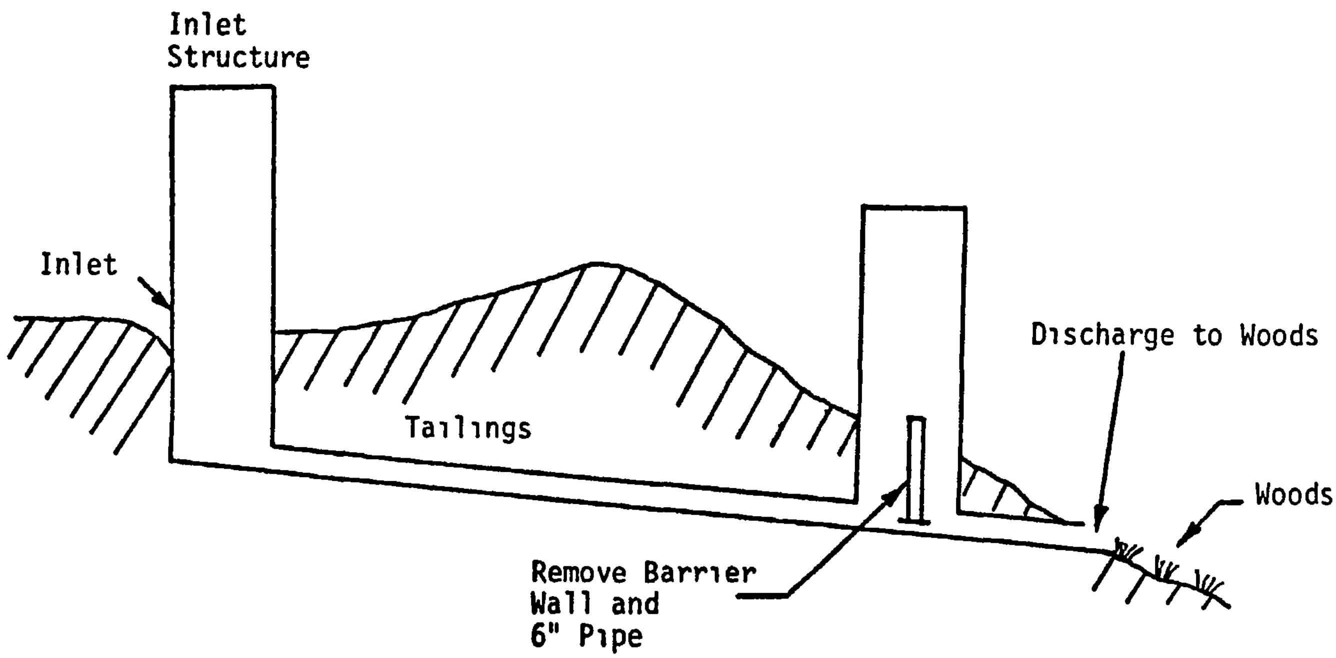

Fig. 32, Profile of Drainage Structure No 1

Costs

Costs were estimated for the following operations

1)	Replacement of eroded material and site preparation	-	$150,000
2)	Seeding, fertilization and placement of wood chips Seed and fertilizer - $7,200 Site preparation and planting - $2,500 } itemization Hauling wood chips - $5,000	-	15,000
3)	Structural modification of the drainage structure	-	2,000
4)	Study of the potential problems of contamination from the landfill operation	-	15,000
5)	Study of fertilization and seeding of the area	-	20,000

It is proposed that an amount of $200,000 should be sufficient for correction of the major problems associated with the tailing pile near St Francois Co

APPENDIX A

Physical Properties of Tailing Materials

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Appendix A

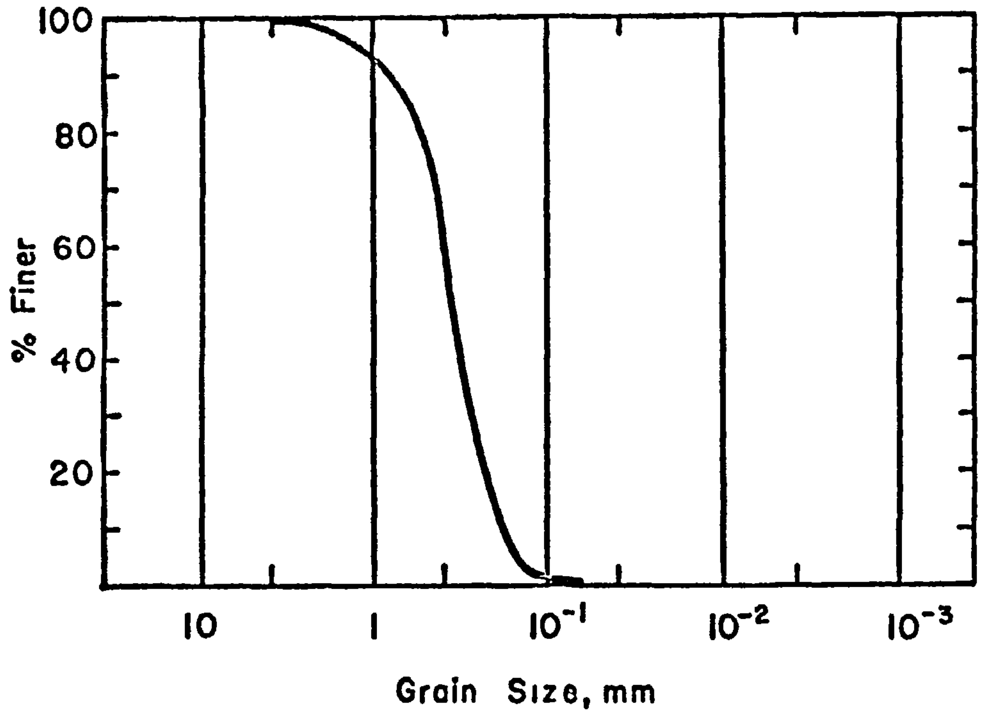
Classification of Tailings Materials

Visual inspection of the tailings pile indicated that soil matter was distributed in a manner characteristic of the hydraulic fill construction method Relatively coarse material was distributed along the perimeter banks and near the remains of the slurry pipeline The material towards the interior of the pile has a much higher percentage of fines Field sampling operations were concentrated in the vicinity of the major erosion site The ore stockpile located south of the tailings pile was also sampled

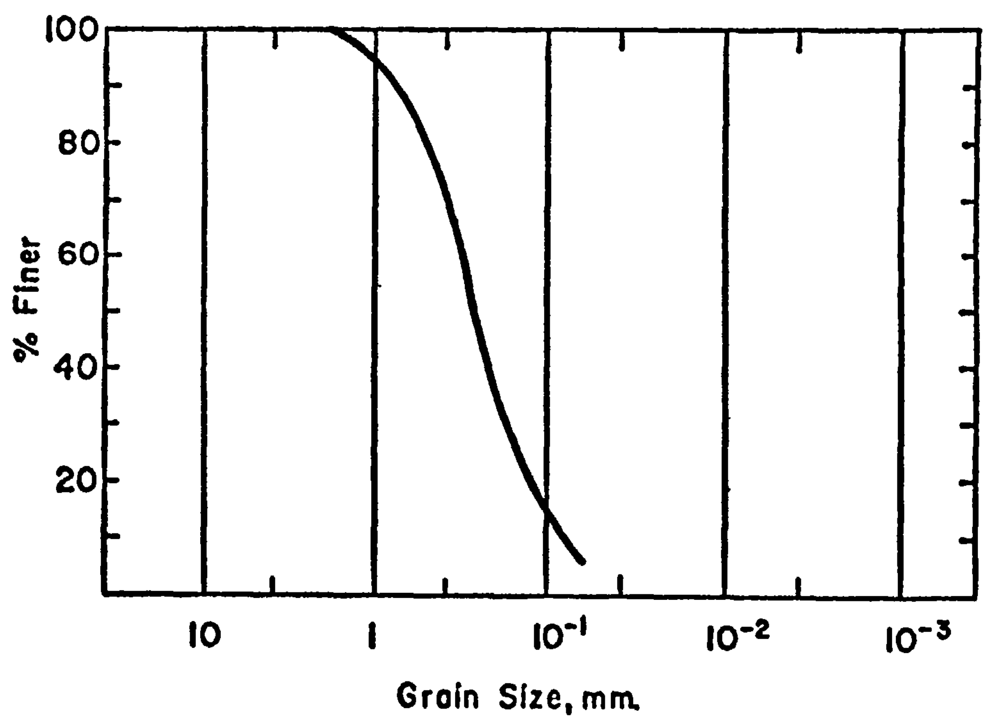
Grain size distribution curves were obtained using mechanical sieve analysis and/or the hydrometer method in cases where significant quantities passed the #200 sieve (0 075 mm grain size) On the basis of these curves, the material in the tailings pile can be divided into three broad categories

The perimeter banks consisted of coarse to medium sands (Samples #2,4,5,8,13, and 14) Grain size distribution curves for this material are shown in Figure A 1 The interior region of the tailings pile consisted of fine to silty sands (Samples #1,7,9,10,11,12, and 16) Grain size distribution curves for this material are shown in Figure A 2 Mottled grey-blue and grey-brown clay was distributed in well-defined lenses ranging in thickness from several inches to about two feet (Samples 3,6,17, and 18) These lenses were clearly visible at various depths along the sides of the different erosion sites A representative grain size distribution curve for the clay material is shown in Figure A 3

The material in the ore stockpile is a medium sand (Sample 15) A grain size distribution curve for this material is shown in Figure A 4

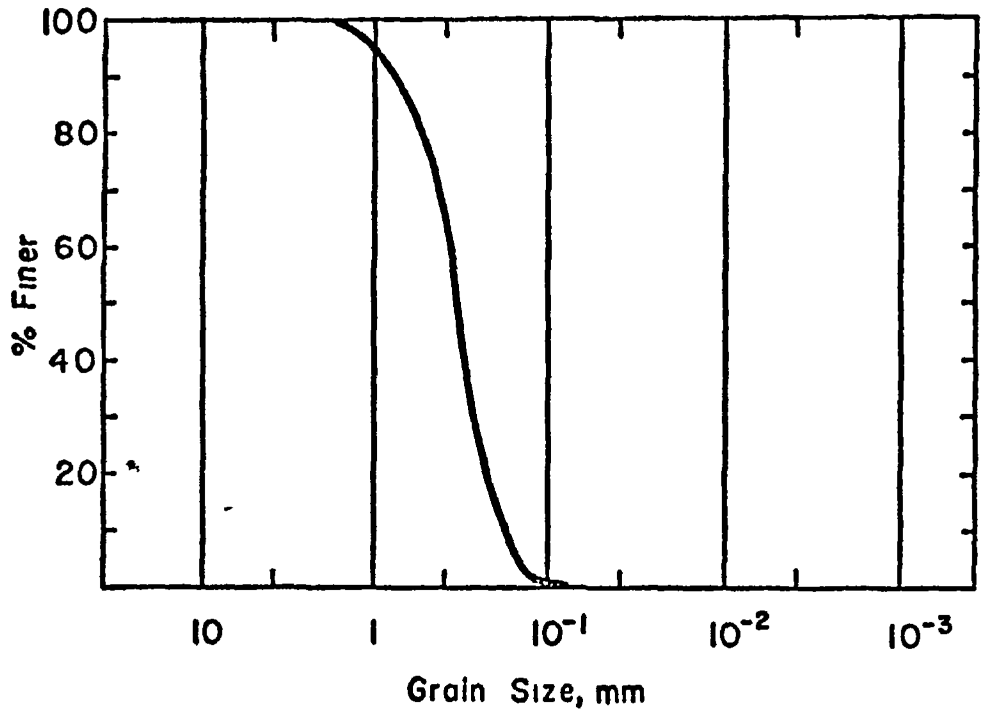


(a) Sample #2

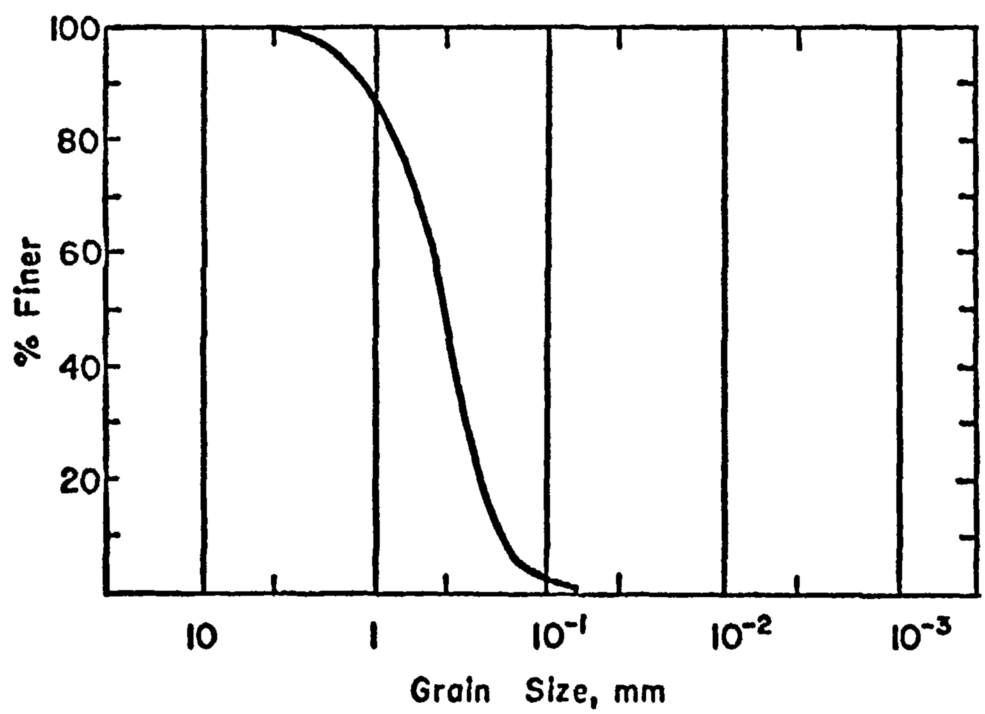


(b) Sample #4

Fig A 1 Grain Size Distributions - Perimeter Bank Material

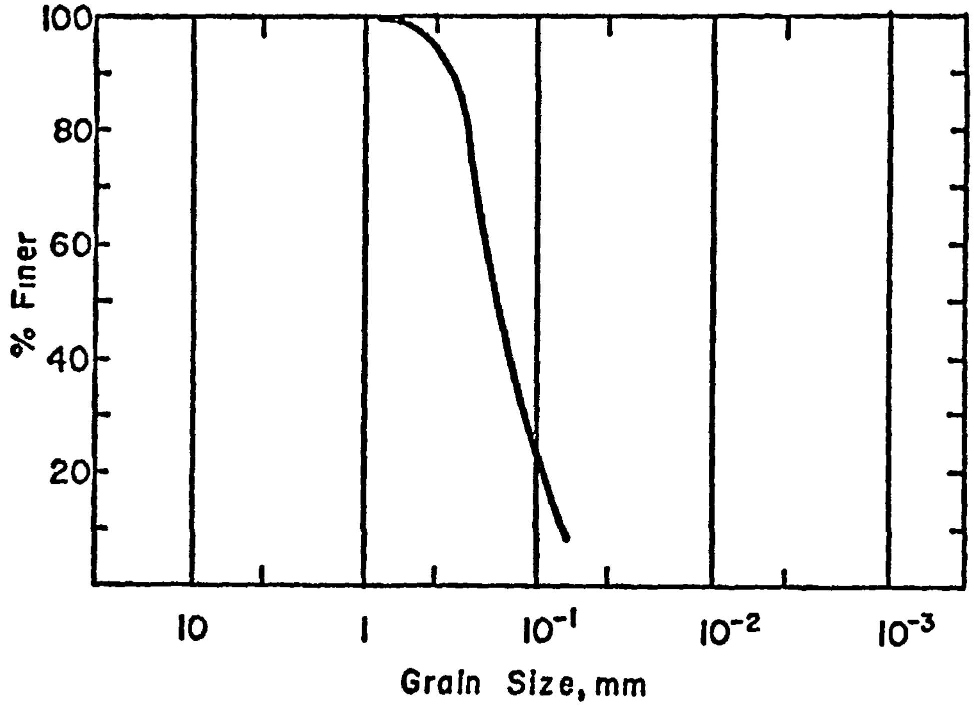


(c) Sample #5

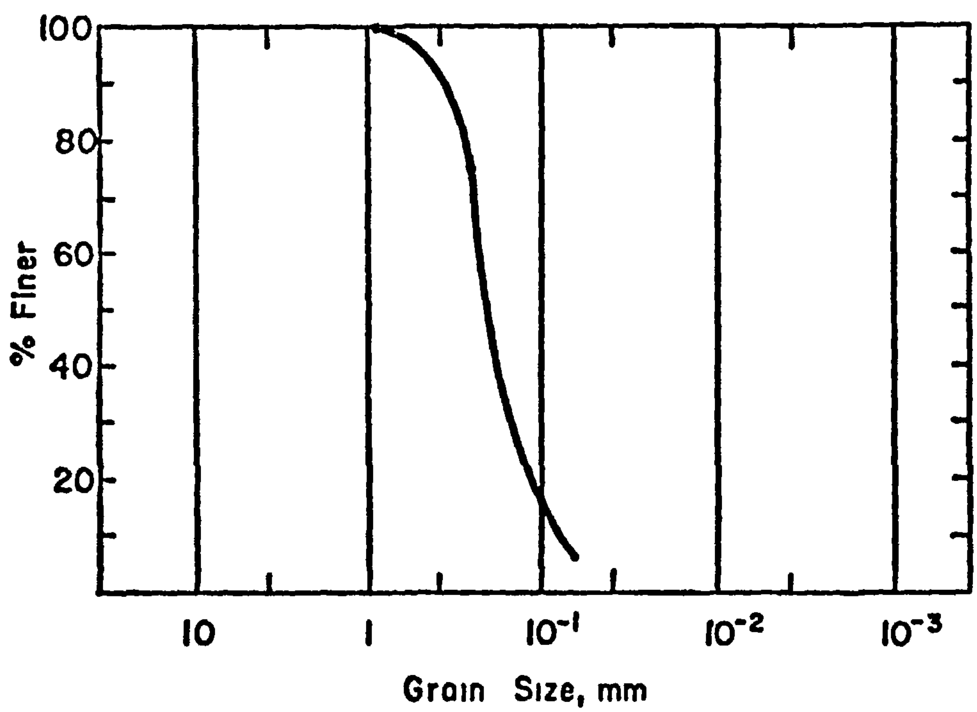


(d) Sample #8

Fig A 1 (con't) Grain Size Distributions - Perimeter Bank Material

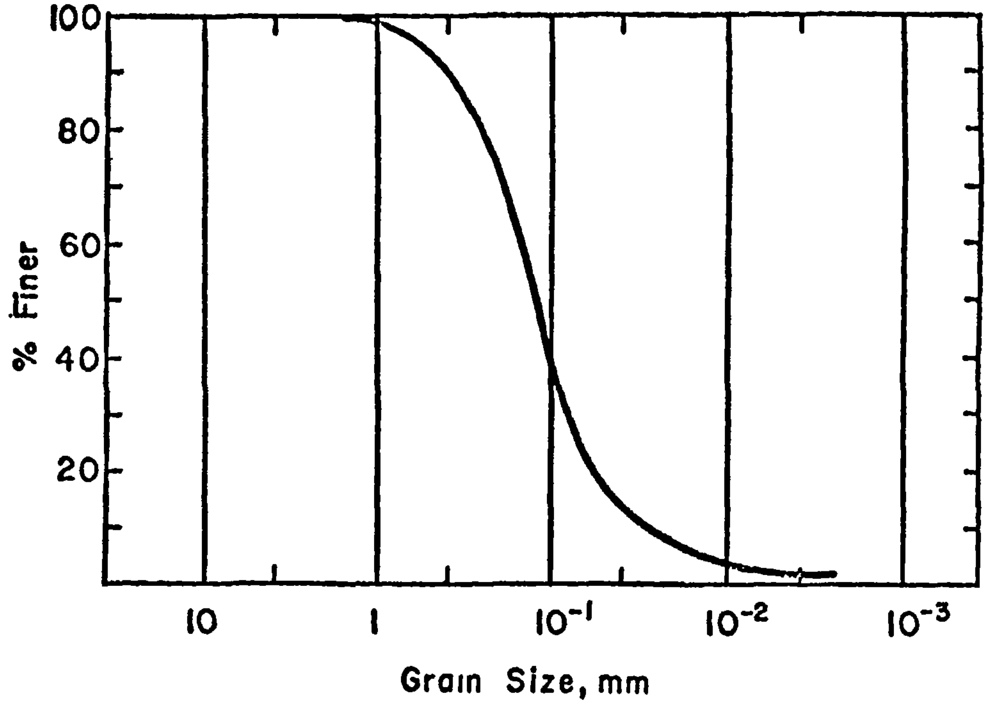


(e) Sample #13

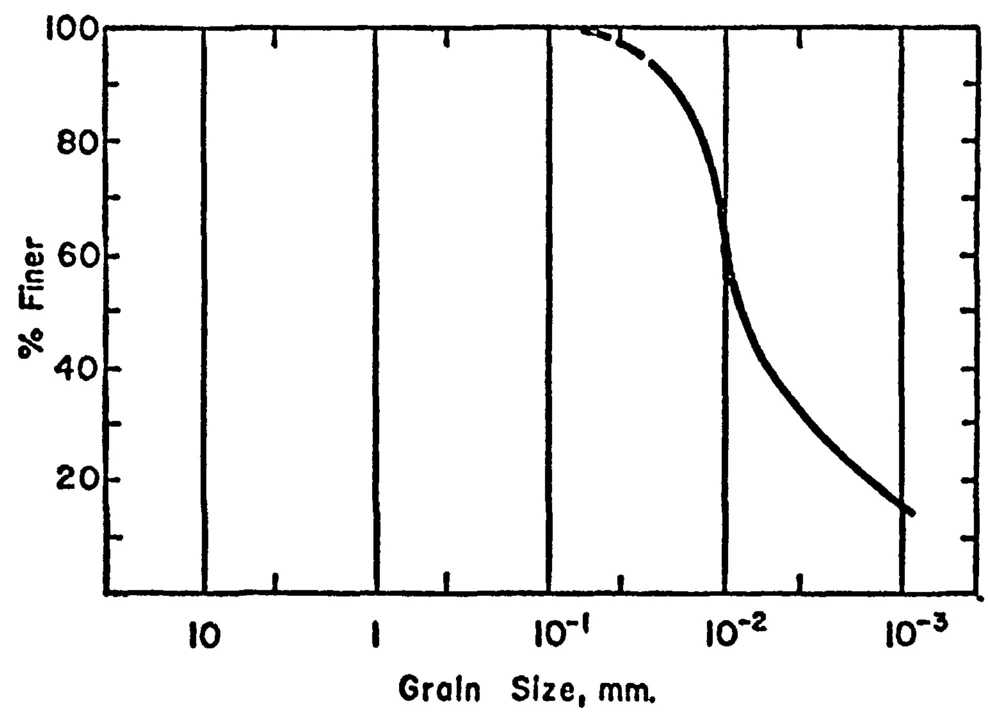


(f) Sample #14

Fig A 1 (con't) Grain Size Distributions - Perimeter Bank Material

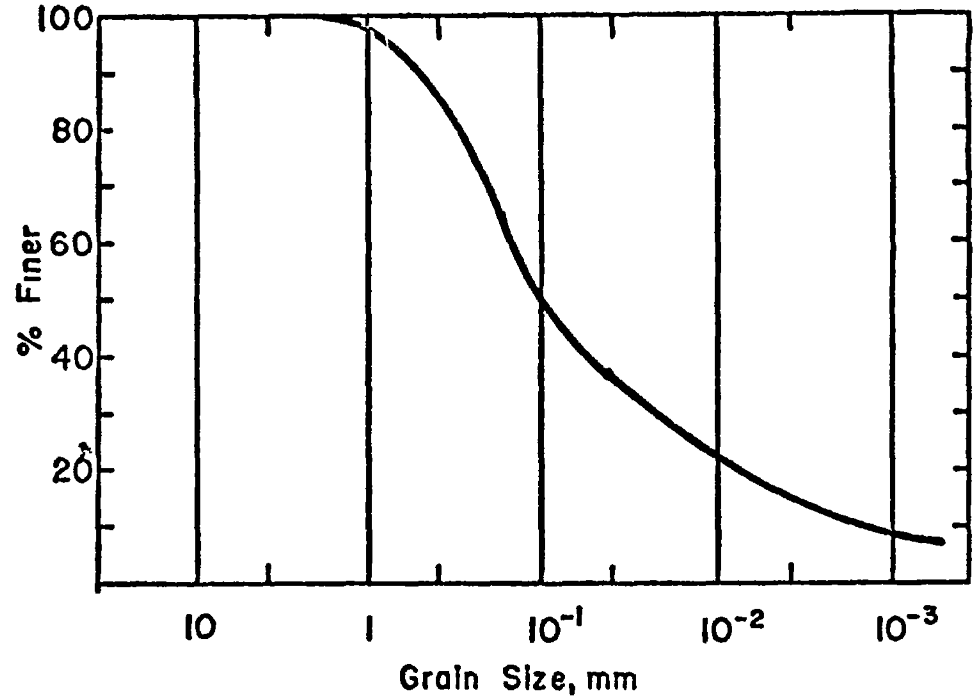


(a) Sample #1

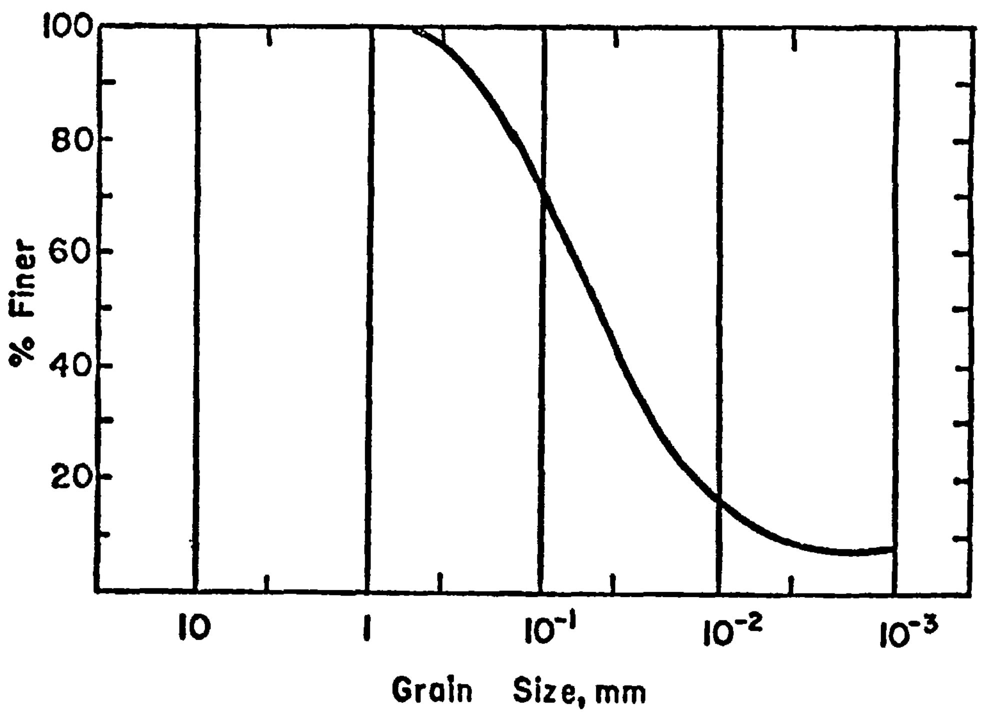


(b) Sample #6

Fig A 2 Grain Size Distributions - Material from Interior Region of Tailings Pile

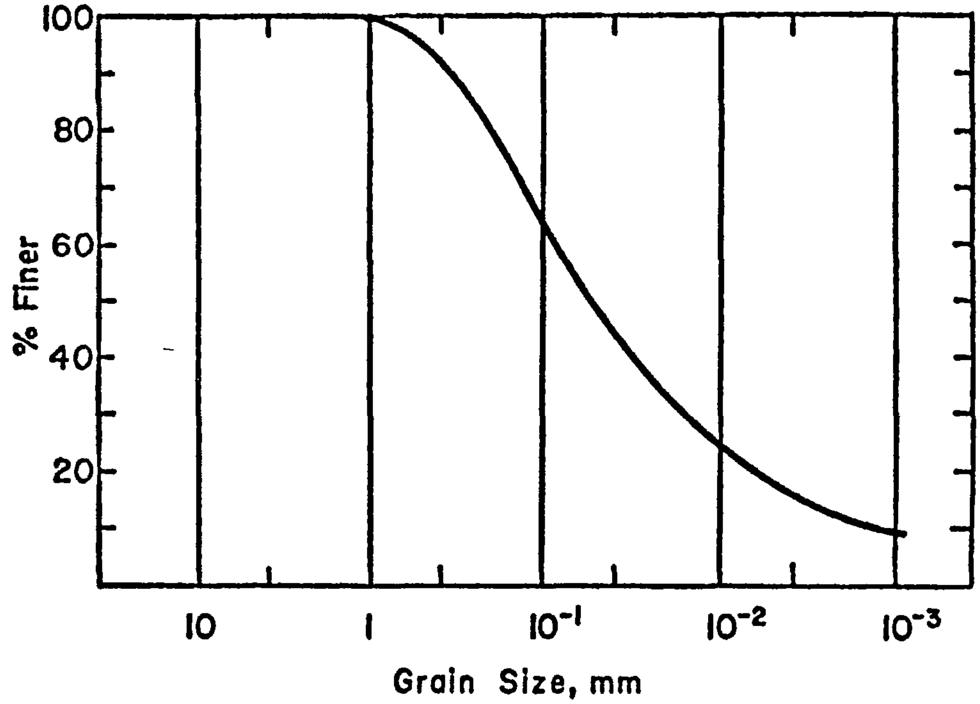


(c) Sample #7

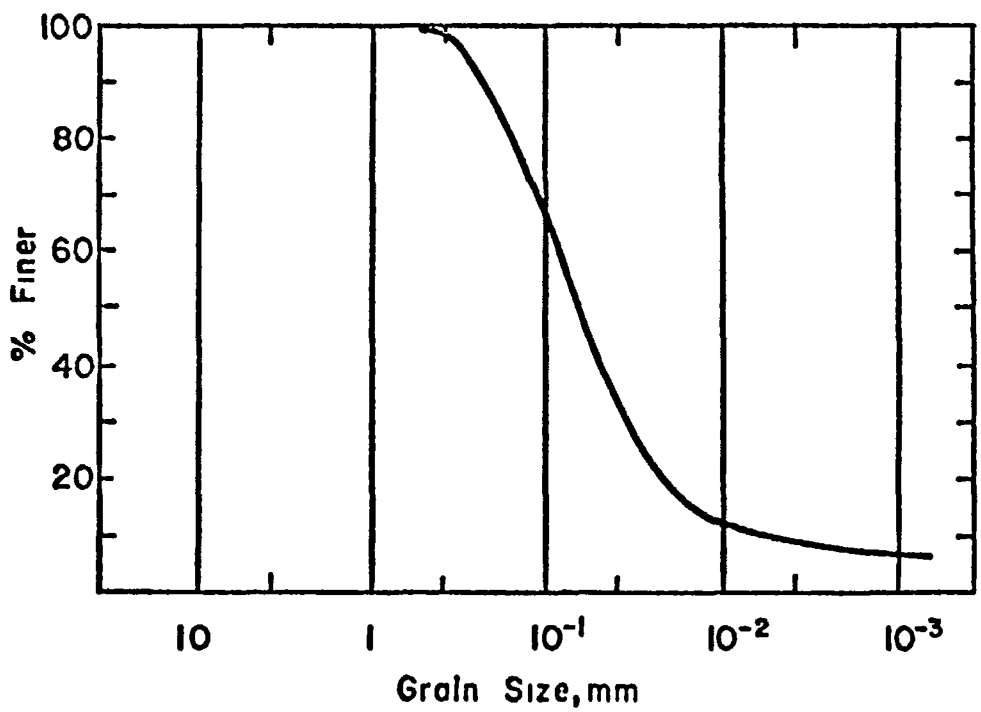


(d) Sample #9

Fig A 2 (con't) Grain Size Distributions - Material from Interior Region of Tailings Pile

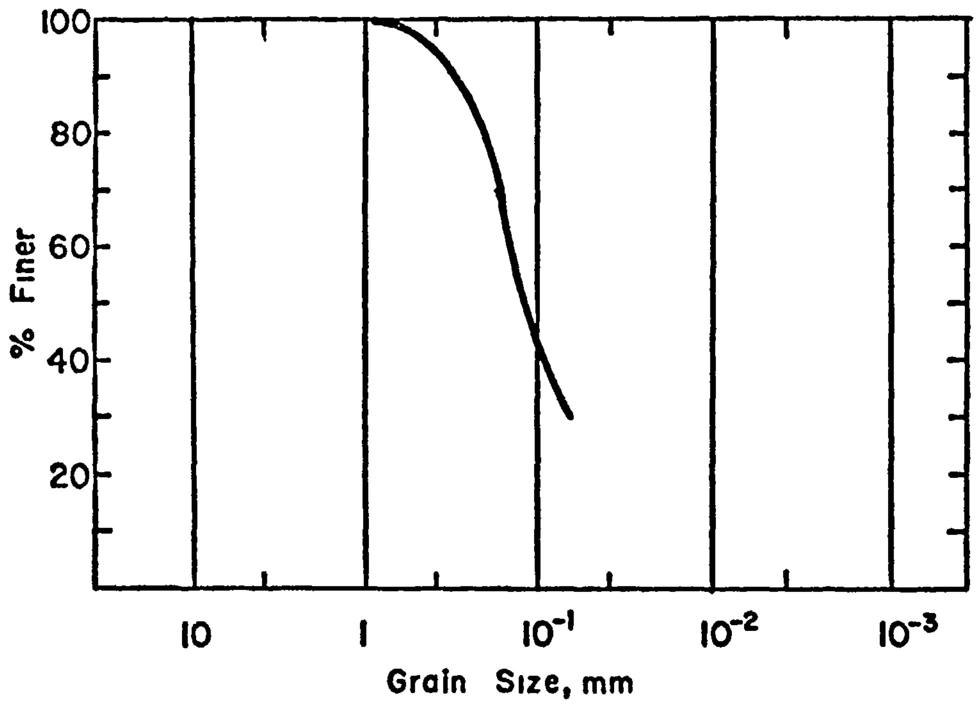


(e) Sample #10



(f) Sample #12

Fig A 2 (con't) Grain Size Distributions - Material from Interior Region of Tailings Pile



(g) Sample #16

Fig A 2 (con't) Grain Size Distributions - Material from Interior Region of Tailings Pile

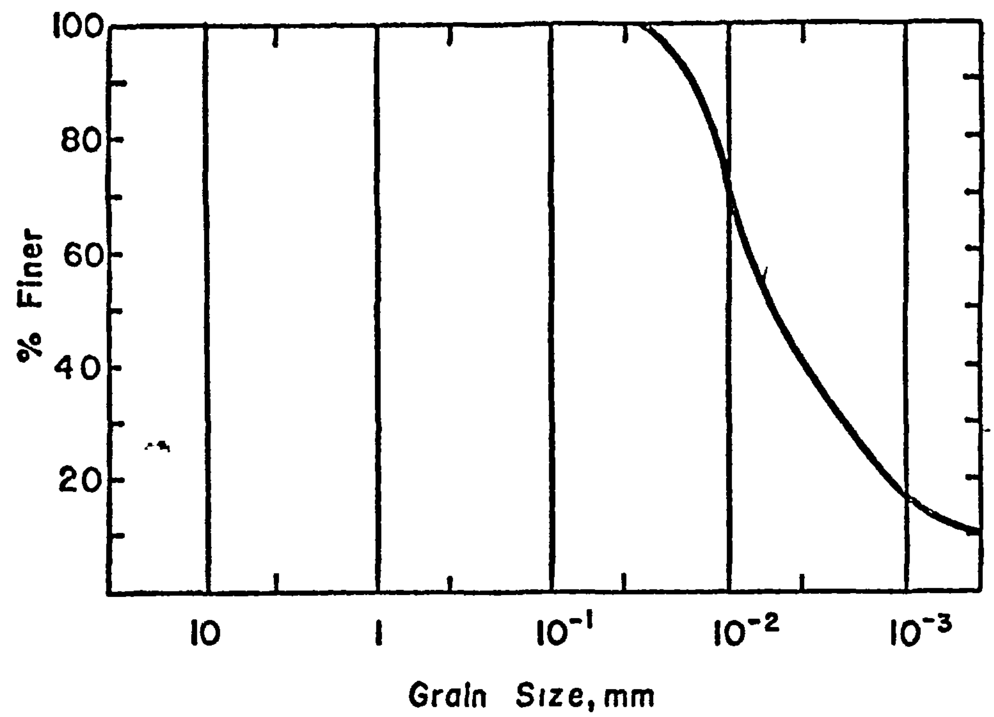


Fig A 3 Grain Size Distribution -
Material from Clay Lense (Sample #3)

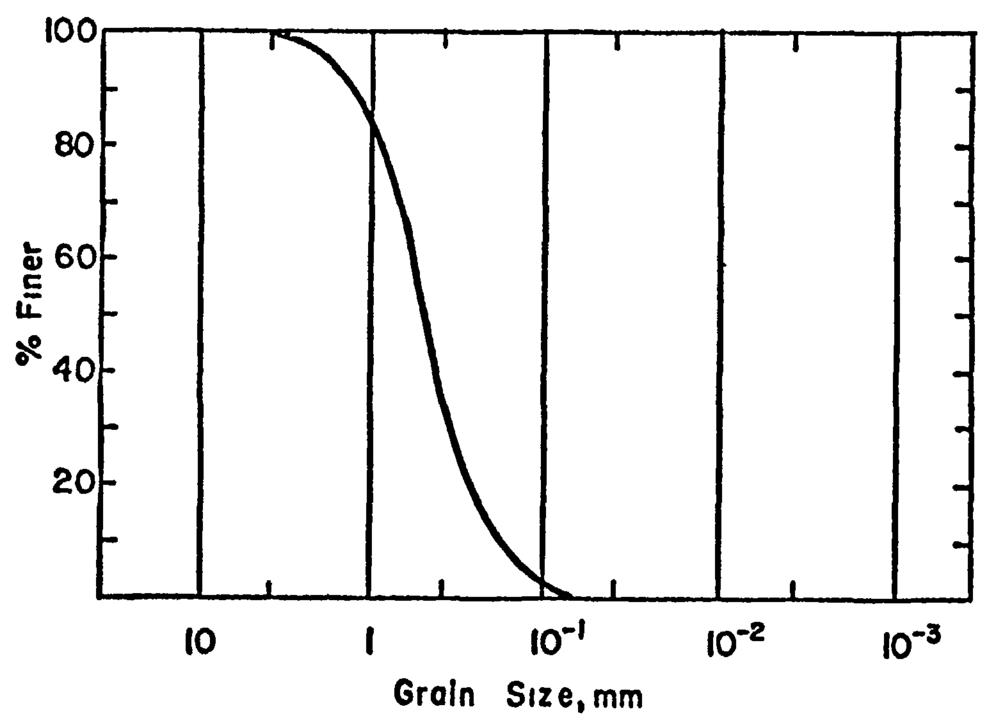


Fig A 4 Grain Size Distribution -
Material from Ore Stockpile (Sample #15)

Index Properties

The fine sands and silty sands of the interior region of the tailings pile were characteristically nonplastic with relatively low values for liquid limit The liquid limit is defined as the water content, described as a percentage of sample weight, above which the material behaves like a viscous fluid Table A-1 summarizes the index properties of representative samples

It was found that the field water content of the material in the interior region of the tailings pile averaged around 10%, well below the liquid limit The material tended to dry out to form a hard, thin layer which helps stabilize the moisture content below the surface

As would be expected of a material with such a high percentage of fines, the coefficient of permeability for this material as determined by the constant head method had an average value of $5\ 5 \times 10^{-5}$ cm/sec With proper contouring of the top of the tailings pile, this low permeability combined with the essentially impermeable clay lenses would likely cause water to form standing pools on the top surface It is believed that the original drainage plan for the tailings pile was based on this characteristic

The specific gravity of the fine or silty sands had an average value of 2 877 with a standard deviation of 0 008 The high and very uniform values for specific gravity can be attributed to the lead content of the tailings material

Liquid limit tests were not performed on the material from the perimeter banks due to the coarser nature of the material All samples from the perimeter bank had less that 10% of the sample pass the #200 sieve Specific gravity values averaged 2 887 with a standard deviation of 0 006, statistically, the specific gravities of the bank material and the interior region material were equal The coefficient of permeability of the perimeter bank material, however, averaged $8\ 6 \times 10^{-3}$ cm/sec

The presence of extensive clay lenses would be a matter of concern in a normal construction site As no permanent structures are to be placed on the tailings pile, however, these lenses are not as critical as they might normally be regarded In addition, tests showed that the material is a low-plasticity, inactive clay Table A-2 summarizes the index properties of the four samples taken from various clay lenses

In Table A-2, the plastic limit is the water content below which the soil becomes nonplastic The range of water content over which the soil is plastic is defined by the Plasticity Index which is found by the numerical difference between the liquid limit and the plastic limit By comparison, a highly plastic clay would be expected to have a liquid limit greater than 50 and a Plasticity Index greater than 30

It is significant to note that the field water content of the clay material was found to be very near the liquid limit The high moisture content of the clay was verified by observations in the field Several clay lenses exposed in the erosion sites were seen to be "weeping" with viscous streams of clay running down the sides of the slopes

The low activity of the clay material was also verified by a series of consolidation tests performed on remolded samples In a consolidation test, a saturated soil sample 2½ inches in diameter and 1 inch thick is placed in a metal ring and a vertical load is applied Under the action of the sustained vertical load, the vertical deformation of the sample is measured This deformation is due primarily to the pore water in the saturated sample being gradually expelled from the void spaces, elastic deformation is negligible Since the coefficient of permeability of a clay is so small, it may take 24 hours or more for all or most of the deformation to occur under a given constant load For active, highly plastic clays, such tests are important in determining the long-term time-settlement characteristics of the material

For the material from the clay lenses, loading was started at 0 5 tons per square foot and doubled every twenty-four hours until a loading of 16 tsf was completed Vertical deformation was measured at various time intervals during each twenty-four hour period

Representative time-deflection plots are shown in Figures A 5 and A 6 It is seen that the major fraction of the total settlement for each loading increment occured within the first few minutes of loading While remolding the samples disturbs the actural clay structure as found in the field, it can be concluded that the clay material in the tailings pile is not an active clay from a time-settlement point of view

Shear Strength

The direct shear test was used to evaluate the shear strenght of the tailings pile material

A schematic diagram of a direct shear test apparatus is shown in

Figure A 7. A 2½ in diameter specimen about 1½ in thick is placed in a cylindrical shear box The shear box is divided into two halves separated by a small gap A constant normal load, P_v, is applied vertically While the lower shear box is held stationary, a gradually increasing shear load, P_h, is applied The specimen is assumed to fail along the horizontal shear plane By applying the shear load in a controlled-deformation manner, the descending branch of the horizontal load-displacement curve can be obtained Dividing the normal load and the peak shear load by the cross-sectional area of the cylindrical sample, the normal stress and the shear stress at failure is obtained By definition, this stress state is a point on the failure envelope for the soil, as shown in Figure A 8 According the the Mohr-Coulomb failure criterion, the failure envelope is a straight line given by

$$\tau = c + \sigma \tan \phi$$

where

τ = shear strength

c = cohesion

σ = normal stress

ϕ =angle of internal friction

Several tests are performed at different levels of normal load and a straight line constructed through the points to define the Mohr-Coulomb envelope

For a cohesionless material, c=0, and the angle of internal friction is the single descriptive parameter The angle of internal friction for a cohesionless soil such as the perimeter bank material is theoretically equal to the maximum angle from the horizontal of a stable slope for that material In fact, the naturally occurring slope angle, called the angle of repose, is theoretically equal to the friction angle Therefore, the primary intent of the direct shear test series in this application is the determination of the internal friction angle

Figure A 9 shows a series of typical horizontal load-deflection curves obtained from five direct shear tests conducted at five different levels of normal load for a sample from the perimeter bank (Sample 8) From these curves, the peak value of shear load can be obtained The resulting values of shear stress and normal stress, together with similar values from replicate tests, are plotted in Figure A 10 A least-squares curve fit was performed on the data points yielding a friction angle of

38° The cohesion value of about 2 psi which resulted from the curve-fit is well within acceptable experimental error limits for a cohesionless material

Figures A 11 and A 12 show Mohr-Coulomb envelopes for another perimeter bank sample (Sample #14) and for the ore stockpile material (Sample #15), respectively Statistically, the internal friction angle values have a 95% confidence interval of about 2 5°

The internal friction angles for the perimeter bank material are several degrees higher than typically encountered in normal sands with similar grain size characteristics This may be accounted for by noting that the tailings pile material is a very recently formed material from a geological point of view Not having been subjected to the normal weathering sequence of naturally occurring sands, the tailings material can be expected to be more granular with a correspondingly higher internal friction angle

As described earlier, the material in the interior region of the tailings pile tended to form a hard, thin crust as it dried This apparent cohesion is typical of such sands and is due to capillary tensions which develop as the soil dries This cohesion diminishes or disappears as the moisture content increases Direct shear tests on several remolded, air-dried samples yielded a cohesion of 29 psi and a friction angle of 27° Increasing the moisture content to 8 4% resulted in a cohesion of only 6 psi and a friction angle of 36° Figure A 13 shown the Mohr-Coulomb envelope for a different sample of the interior region material which was finely pulverized and tested dry The value of cohesion of 3 psi from Figure A 13 is within the limits of experimental error for a cohesionless material

Conclusions

The tailings pile as a whole appears to be stable The steep slopes of the perimeter banks appear conditionally stable, these slopes have apparently assumed their natural angle of repose The soil along these slopes, however, is a dry, loose material and is stable provided it is not grossly disturbed While the slopes themselves are steep enough to preclude ready travel of any heavy earth-moving equipment which might be used in the repair of the erosion sites, the use of such equipment near the crests of the slopes may lead to localized slope failures Extreme caution should be exercised in the use of such equipment along the perimeter banks

The near-vertical sides of the major erosion site are unstable During the course of this investigation, several local slope failures were observed The loose material added to the bottom of the erosion site does not appear to be washing into the river, however, and once the site is filled, it will no longer be a matter of concern

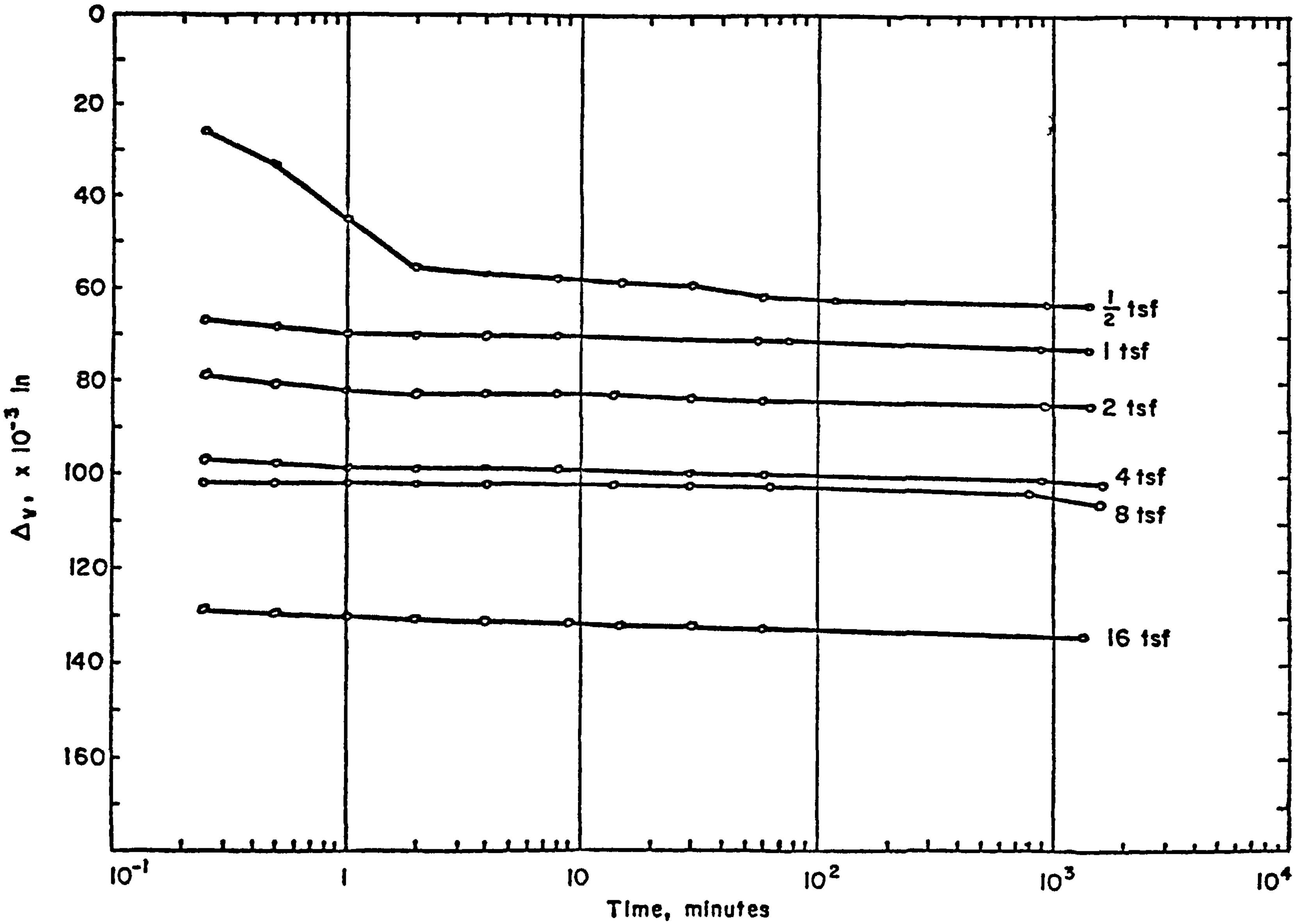


Fig A 5 Time-Deflection Curves, Sample #18

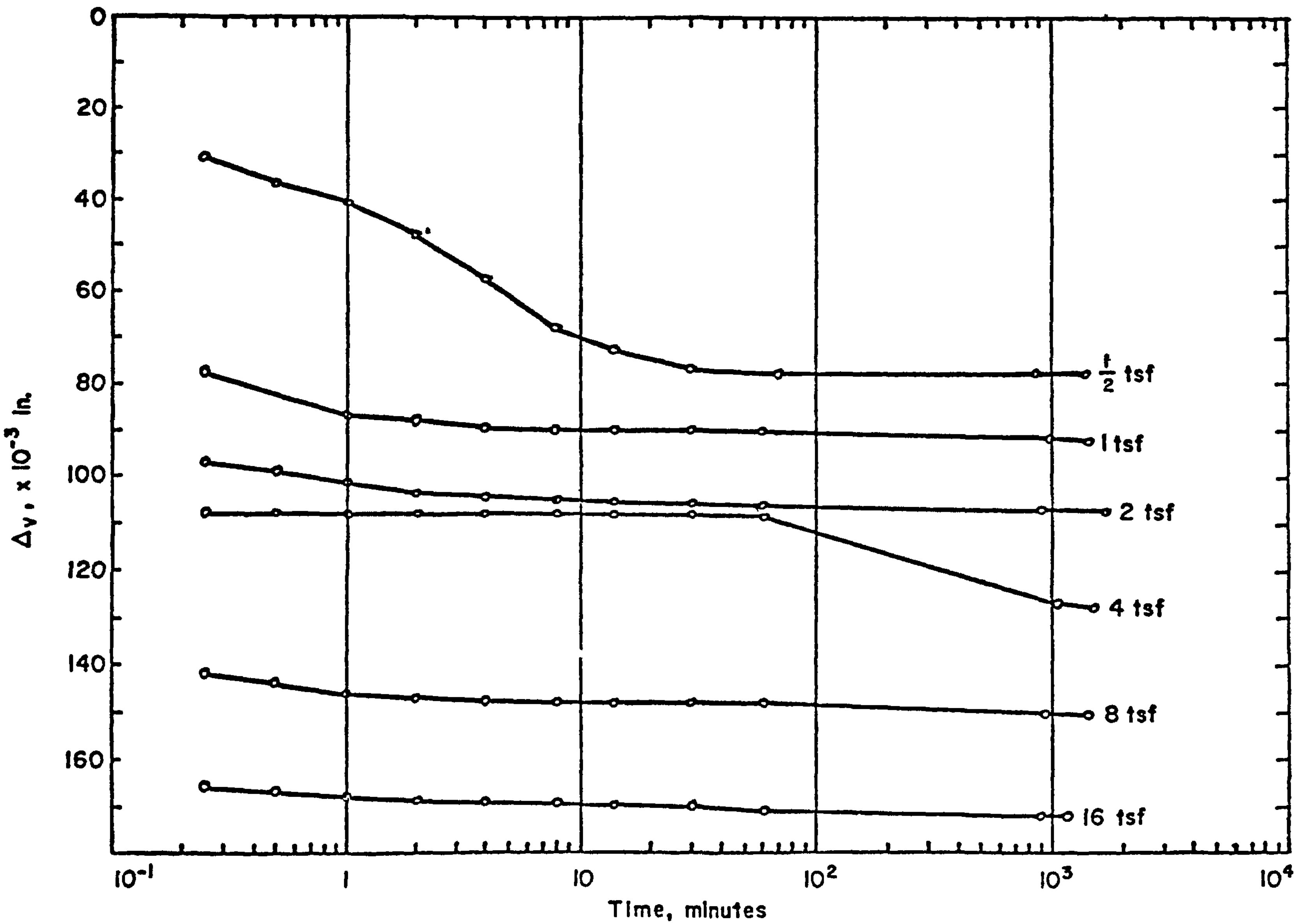


Fig A 6 Time-Deflection Curves, Sample #17

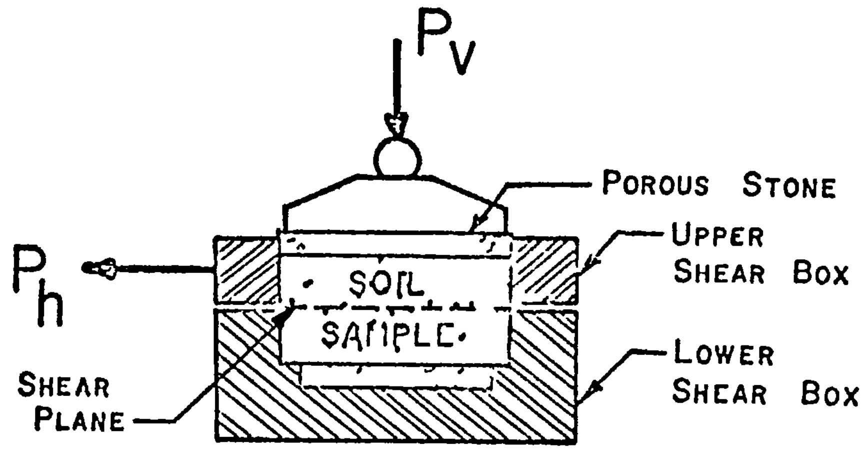


Fig A 7 Schematic Representation of the Direct Shear Test Apparatus

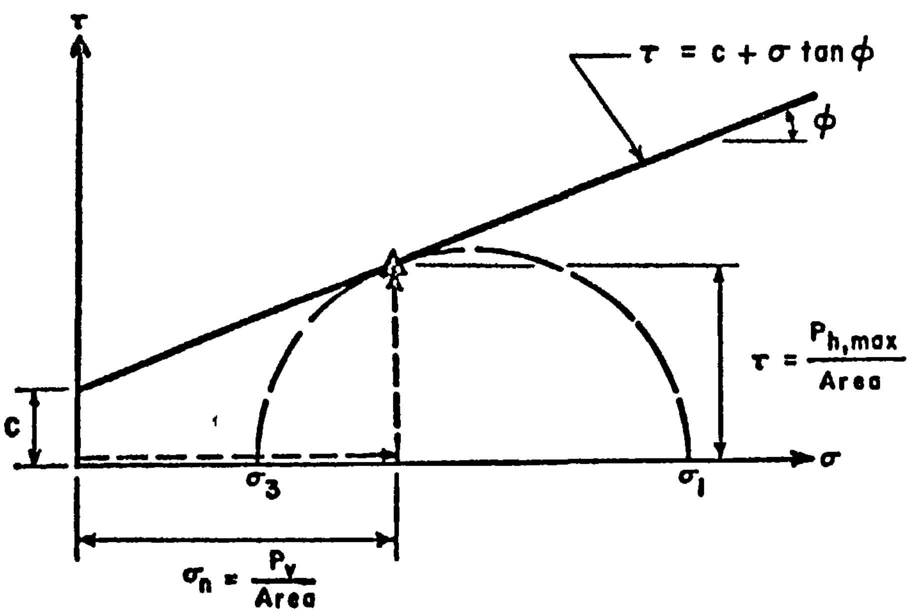


Fig A 8 Determination of a Point on the the Mohr-Coulomb Failure Envelope

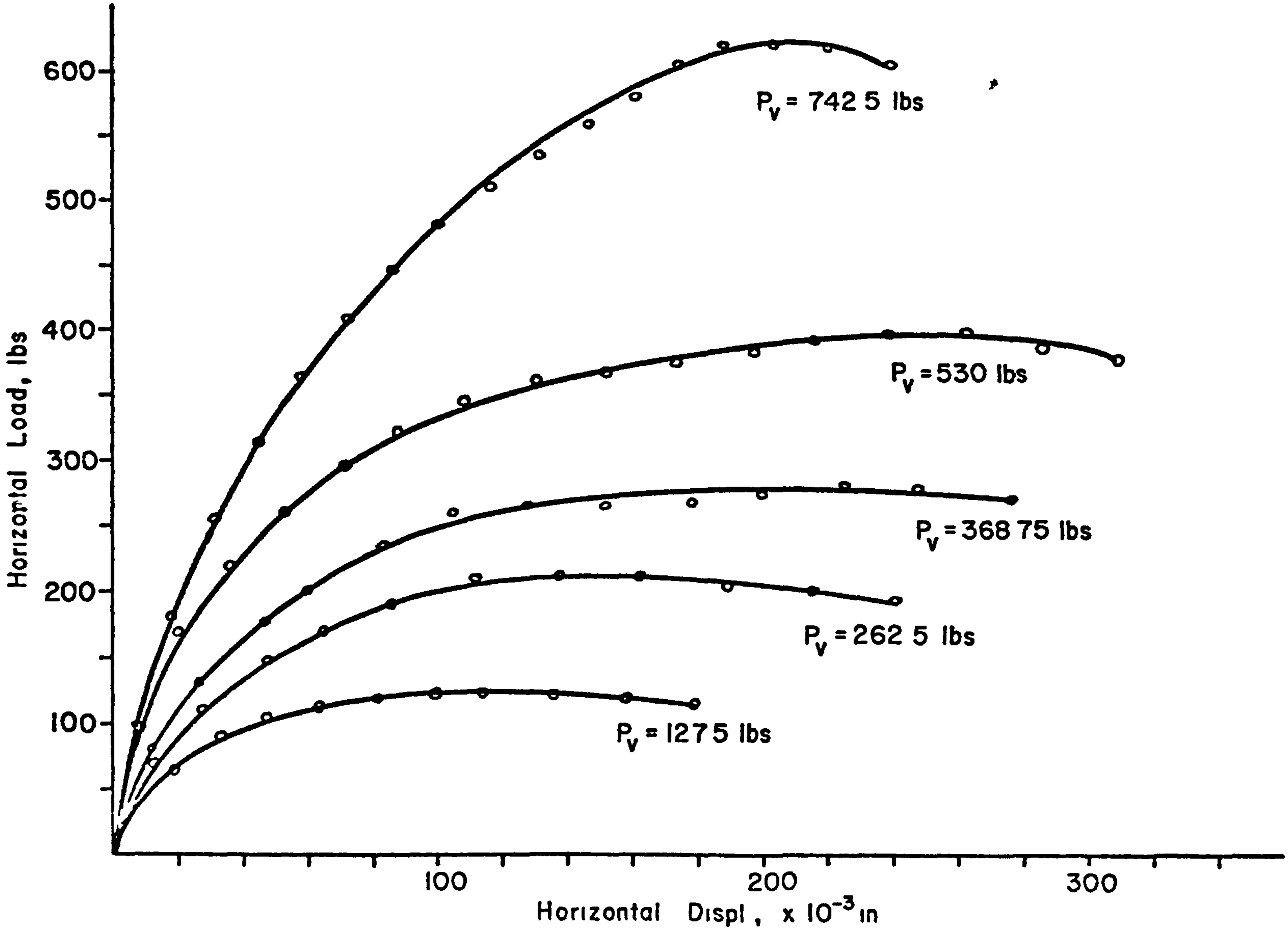


Fig A 9 Typical Horizontal Load-Displacement Curves, Perimeter Bank Material (Sample #8)

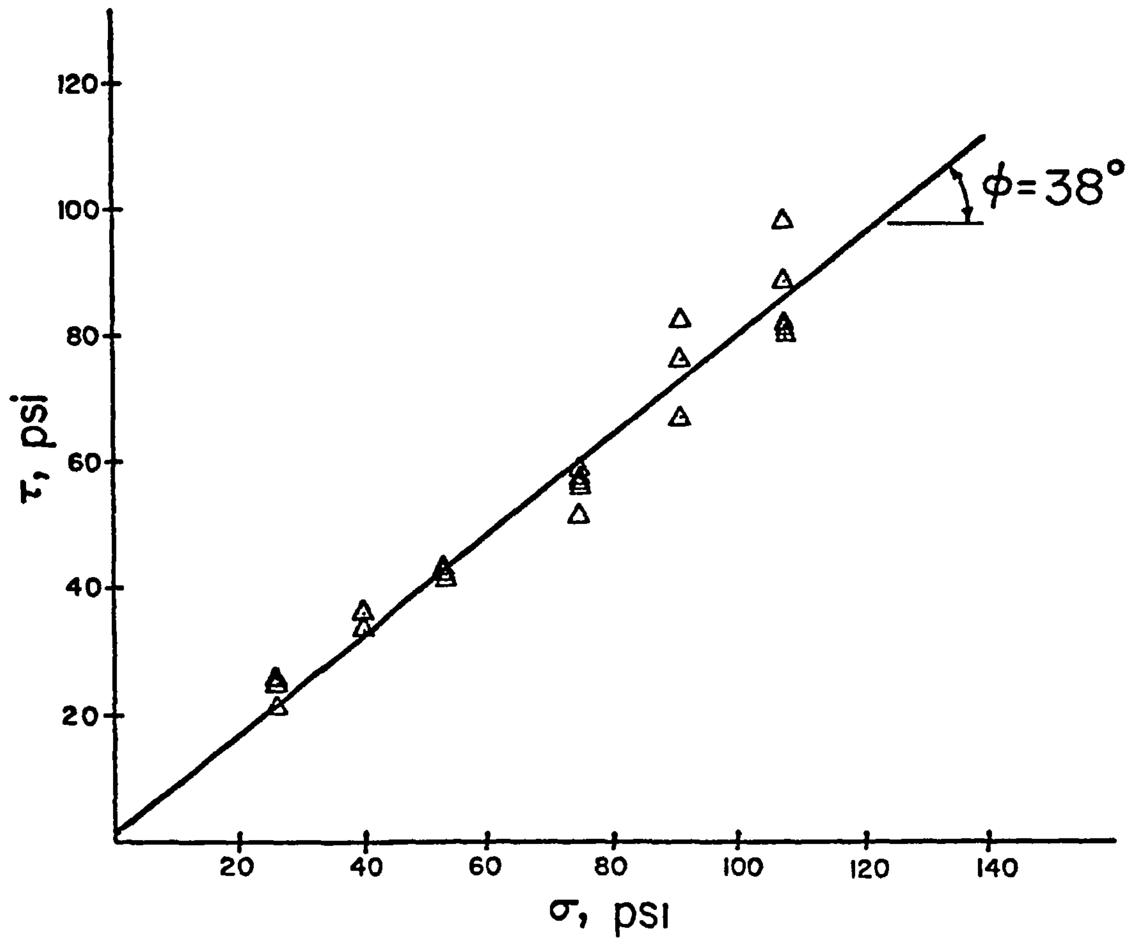


Fig A 10 Mohr-Coulomb Envelope, Perimeter Bank Material (Sample #8)

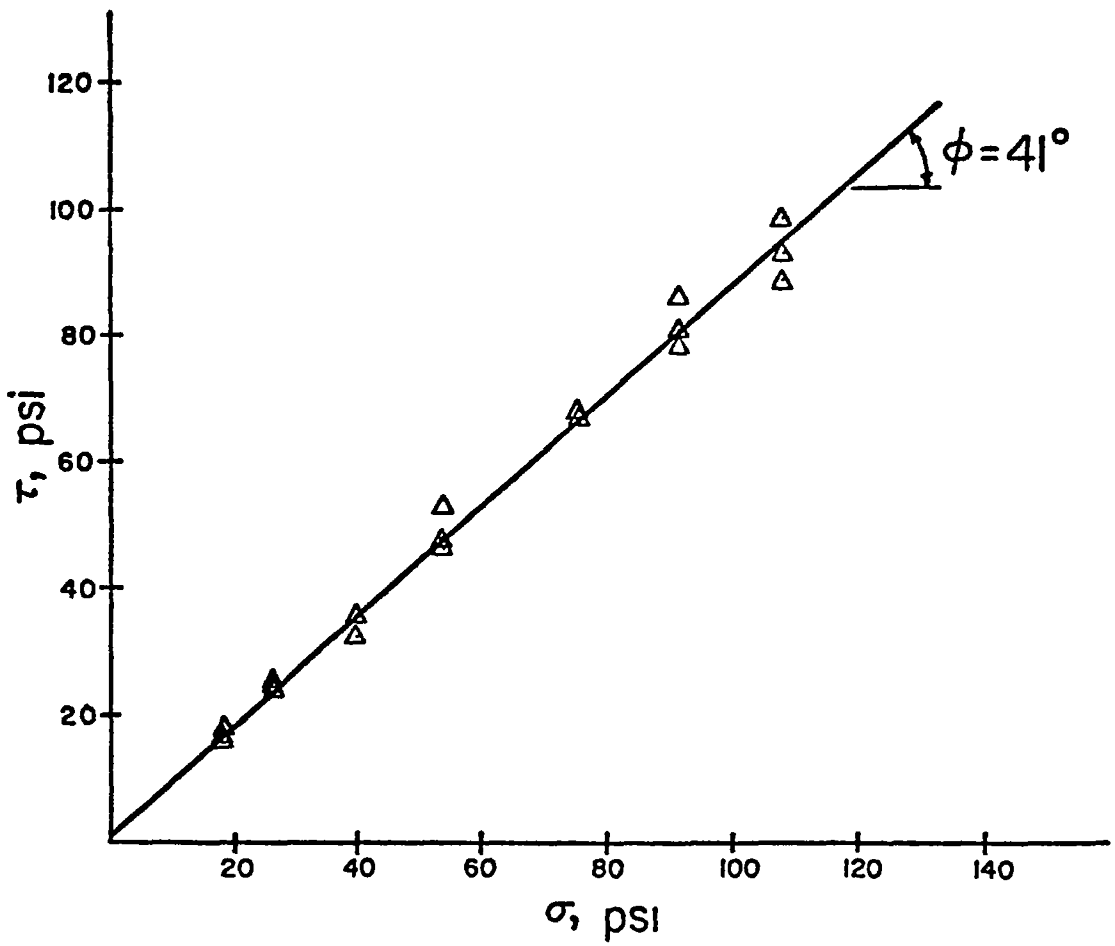


Fig A 11 Mohr-Coulomb Envelope, Perimeter Bank Material (Sample #14)

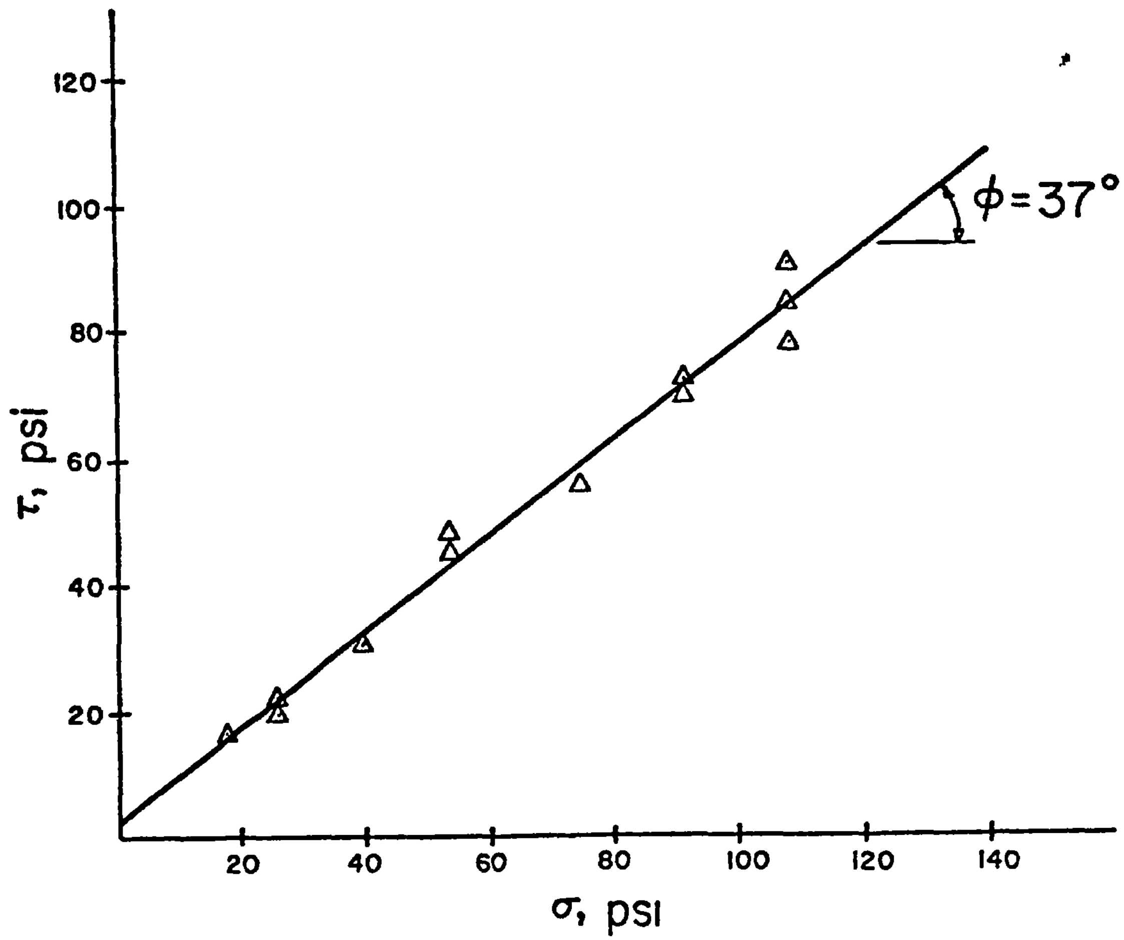


Fig A 12 Mohr-Coulomb Envelope, Ore Stockpile Material (Sample #15)

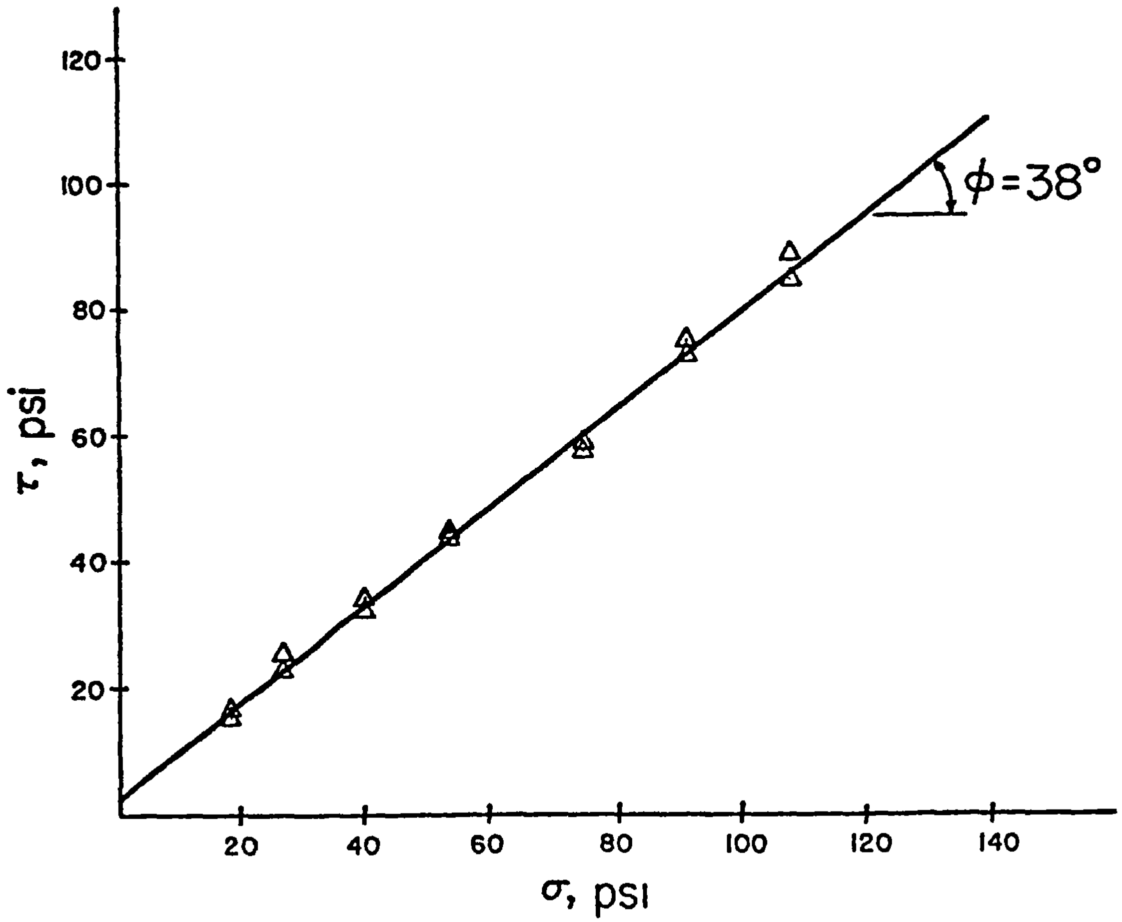


Fig A 13 Mohr-Coulomb Envelope, Interior Region Material (Sample #16)

	SAMPLE			
	#3	#6	#17	#18
Liquid Limit, %	27 3	28 9	30 5	32 2
Plastic Limit, %	18 1	19 0	20 9	18 6
Plasticity Index	9 2	9 9	9 6	13 60
Specific Gravity	2 889	2 874	2 864	2 877

Table A 2 Index Properties of Clay Material

	SAMPLE			
	#9	#10	#11	#12
% Finer, #200 Sieve	38 3	21 3	20 4	32 2
Liquid Limit, %	16 02	16 67	16 92	18 31
Specific Gravity	2 876	2 880	2 866	2 876

Table A 1 Index Properties, Fine/Silty Sands from Interior Region of Tailings Pile

APPENDIX B

Potential of Tailings For Supporting Growth

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Erosion Problem

Many problems exist at the Desloge mine site The main problem however is overland flow which is currently causing the development of a large gully at the site Due to the non-cohesive properties of this soil material, little possibility exists for the development of safe overland or surface drainage Two feasible solutions to this problem do exist One solution would be to locate previous underground drains and repair to a satisfactory working condition A second solution is to establish a complete sub-surface drainage system with surface risors similar to agriculture type drains found in pothole areas of Iowa and Illionis This second alternative has one limitation which is the requirement that the movement of the sand like material be stopped to insure a stable and controlled surface topography

The second most important problem at the site is the lack of established ground cover This allows the wind to move a considerable amount of the material The solution to this problem is probably a combination of shelter belts (either of trees and other tall vegetation or fences and other mechanical devices) and the establishment of close growing grasses The shelter belts will lift the winds reducing the major movement and will thus help protect the grass from the abrasion of sand particles Once the grass gets established, an adequate cover should exist to completely stabilize the site

LEAD MINE TAILINGS
GRASS EXPERIMENTS

Objective

The objective of this experiment was to obtain preliminary data on the growth of various grasses on lead mine tailing waste and determine various soil amendments that could be used to help in grass establishment

Procedures

Twelve plots, one square foot each, were established on the Agricultural Engineering Farm Each plot was six inches deep and was filled with tailing material brought from the Flat River, Missouri site In addition to a control, three soil treatments were applied sewage lagoon effluent, digested sewage sludge (liquid) and wood shavings Each plot received 40g of 12-12-12 commercial fertilizer Sand lovegrass, switch grass and fescue were the grass seed used In each plot 200 seeds were surface broadcast and 200 seeds were drilled (½" depth) The plots were covered with a lath sunshade and given one inch of water per week

Results

Six weeks after seeding, the number of seeds germinated were counted The results are presented in Table 1 The initial seeding was done in July This is a poor time to seed grass and must be considered in the results

Fescue and switch grass had much better germinations than sand lovegrass The Western native grasses such as sand lovegrass have a reputation for being difficult to establish Drilled seed had much higher rates of germination than surface broadcast seed This is likely due to better moisture availability and less affect due to wind erosion The vast majority of surface broadcast seed that germinated did so along the plot boundaries, where the seed had blown or been carried by water The data confirm the advantage of drilling observed on large seeded reclamation areas in the Flat River area

The general trend for treatments was for the wood shavings and lagoon effluent to increase germination The control, lagoon effluent and sludge plots settled with time, becoming very compact while the wood shaving plots maintained a lighter bulk density and did not compact The wood shaving plots appeared to be drier at the surface

The surface of the lagoon effluent plots were largely covered with algal growth The effluent contained a large concentration of algae and may have acted as seed The algal growth appeared to help stabilize the surface and may account for the increased germination over the control plots

Determination of Water Retension Curves for Lead Mine Tailings

Objective

The objective of this test was to determine the amount of water held in the tailing material at various tensions, both with and with out wood shavings

Procedure

Metal rings one inch in height and 2 63 inches in diameter were fitted with a bottom by attaching a sheet of filter paper to each ring with a rubber band Three rings were filled with mine tailings and three rings were filled with mine tailings and wood chips The rings were placed on a wetting table and filled with additional material as wetting occurred to maintain a constant volume Saturation was achieved by wetting overnight A tension of 4 cm of water head was applied to the wetting table After equilibration, the samples were weighed to determine the mass of water and soil associated with this tension level The samples were then transferred to a pressure plate system where masses (moisture levels) for tension heads of 0 1 bar (102 cm H_2O), 1 bar (1020 cm H_2O), 2 bars (2041 cm H_2O), 4 bars (4083 cm H_2O), 8 bars (8166 cm H_2O), and 14 bars (14290 cm H_2O) were determined The samples were then oven dried to determine the mass of dry soil in each ring The bulk density of each sample was then determined as well as the percent of water by volume for each tension level

Results

The bulk densities observed were 1 54, 1 54, and 1 51 gm/cc for mine tailings and 1 22, 1 12, and 1 22 gm/cc for mine tailings treated with wood chips This verifies the effect of wood chips on bulk density, observed in the field experiment More water (approximately 25% more) was held in the samples containing wood chips at the 4 cm tension level than in the untreated material At the 14 bar tension level (near wilting point for most plants) all samples had about the same moisture content with the exception of one sample which showed high moisture levels at all tension levels (see Fig 1) From this experiment it appears that a wood chip treatment should have more available water for seed germination and plant growth provided the seeds are not broadcast on the surface

Table 1 Number of Seeds Germinating After Six Weeks

	Control		Wood Shavings		Lagoon Effluent		Sludge	
Fescue	8*	13	14	62	11	66	Severe Grass-hopper damage	
Switch	20	35	18	48	13	42	17	7
Sandlove	0	12	7	18	7	2	11	0

* Left column = Surface Broadcast

Right column = Drilled Seed

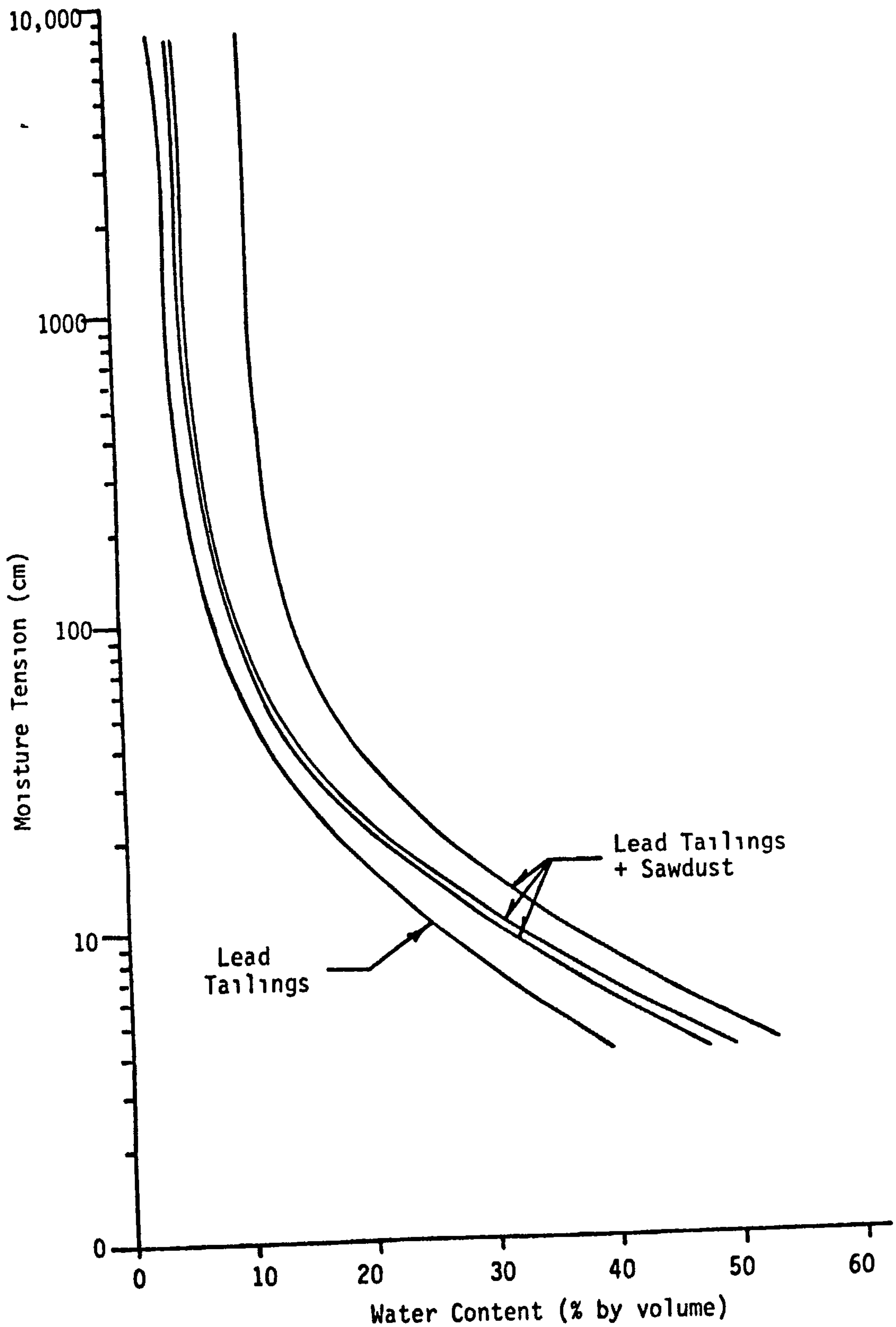

Fig 1 Moisture Release Curves for Mine Tailing Material